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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

A Magazine and an Industry Share a 10th Anniversary and Take Stock of the Future

1947-1957
A Decade of Progress

1957-1967
A Decade of Promise

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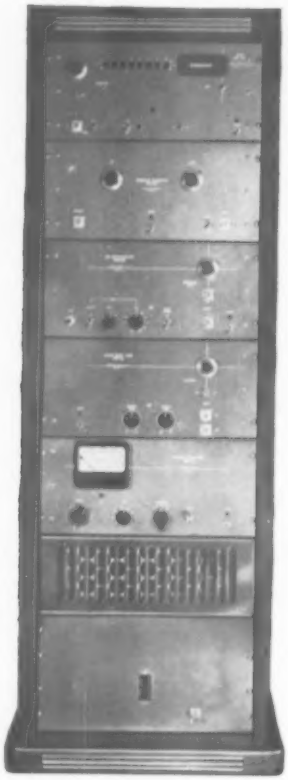

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VOLUME 15 NUMBER 9

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10th ANNIVERSARY ISSUE

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About NUCLEONICS

Author, author. Many is the time over the past ten years that NUCLEONICS has been able to attract into its pages outstanding authors. But rare has been the occasion—in fact, never—that we've been able to bring under one cover as many nuclear luminaries as grace this milestone issue. Of course, we saw to it that it was that way because we felt that if this were to be our last issue—which we can assure you it isn't—we wanted to go down in a blaze of glory.

With this unprecedented lineup of contributors, we decided that another precedent was merited—publication of authors' pictures. Most of them were taken especially for us, including Amasa Bishop with the Arc de Triomphe in the background on p. 128 (our Paris correspondent, who set this up, said, "We walked him around the Place de la Concorde for half an hour . . . ").

Although most of the authors are quite well known to our readers, we thought some additional information on a few of them beyond that given in the affiliation listings would be of interest:

Strauss, p. 77—In our invitation to the AEC chairman to write the dedication, we said we "can think of no other person in the atomic world who would be more appropriate. As a member of the first Atomic Energy Commission and as chairman of the present one, your service for the peaceful atom has spanned this first decade."

Allardice-Trapnell, p. 84—Sidekicks throughout AEC days, both have had responsible public information posts in AEC and later worked very intimately with top AEC officials. Allardice then went to the Joint Committee on Atomic Energy staff and played a key role in the drafting of the new law. There probably isn't a better informed pair on the behind-the-scenes atomic story.

Davis-Roddis-Goodman, p. 90—To get the government reactor view, we went to the three top AEC specialists. Ken Davis, a chemical engineer, got into the reactor business at Livermore. Lou Roddis got his feet wet as a Navy officer at Oak Ridge's Clinch College of Nuclear Knowledge in 1947 and worked on the Navy nuclear program until he took his present post. And Clark Goodman came in via the academic world at MIT, from which spot he has consulted on nuclear matters since Manhattan Project days. He was an important consultant to NUCLEONICS in its early years.

Starr, p. 94—An oldtimer in the reactor business who got his company started in atomic energy in 1945, he now heads a 1,600 man division.

Zinn, p. 100—Frequently called one of the world's top reactor specialists, he worked on the Fermi reactor in 1942 and then went on to play a very key role in AEC's reactor effort. He now operates a small but fast-growing firm in the not-so-hectic, pleasant climate of Florida.

Sporn, p. 104—As head of the world's largest utility system, he's followed atomic energy closely ever since he predicted today's turn of events so closely in 1946. He chaired an AEC advisory committee on utility industry matters, and now, even though he continues his bearish outlook on nuclear power, he's deeply immersed in several major nuclear projects.

Libby, p. 118—Also a member of an early NUCLEONICS' Editorial Board, he has become this country's principal promoter of radioisotopes from his post as AEC's scientific commissioner. A leading chemist, he played an important role in declassification matters as a Senior Responsible Reviewer for AEC.

Bishop, p. 128—Operating under the shadow of the Eiffel Tower now rather than that of the Washington Monument, he told us, in submitting his manuscript, that "this month has been unusually full, involving an unexpected two-week trip to the States on top of side trips to Belgium, Italy, England and Holland." On his article, he says, "Because of the classification of the Sherwood field, I found this article exceedingly difficult to write . . . If the program were wholly unclassified, I would write a completely different type of article.

Coryell, p. 125—In responding to our invitation, he said, "The only reason I can see why I should be marked as the person to review the progress and promise in nuclear chemistry is that I had my first NUCLEONICS article in October, 1947, in the same spirit." Another reason, we told him, was his pre-eminence in his field.

McCullough, p. 134—Now holds one of the most ticklish and difficult jobs in the industry. A long-time Monsanto employee, he headed their power pile division at Oak Ridge in pre-AEC days, the division that produced this country's first civilian power reactor design. He was on NUCLEONICS' Editorial Board in the early days.

—The Editors

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Coming Features in NUCLEONICS

Next Month—Evaluation of Homogeneous Reactors

Nondestructive Testing

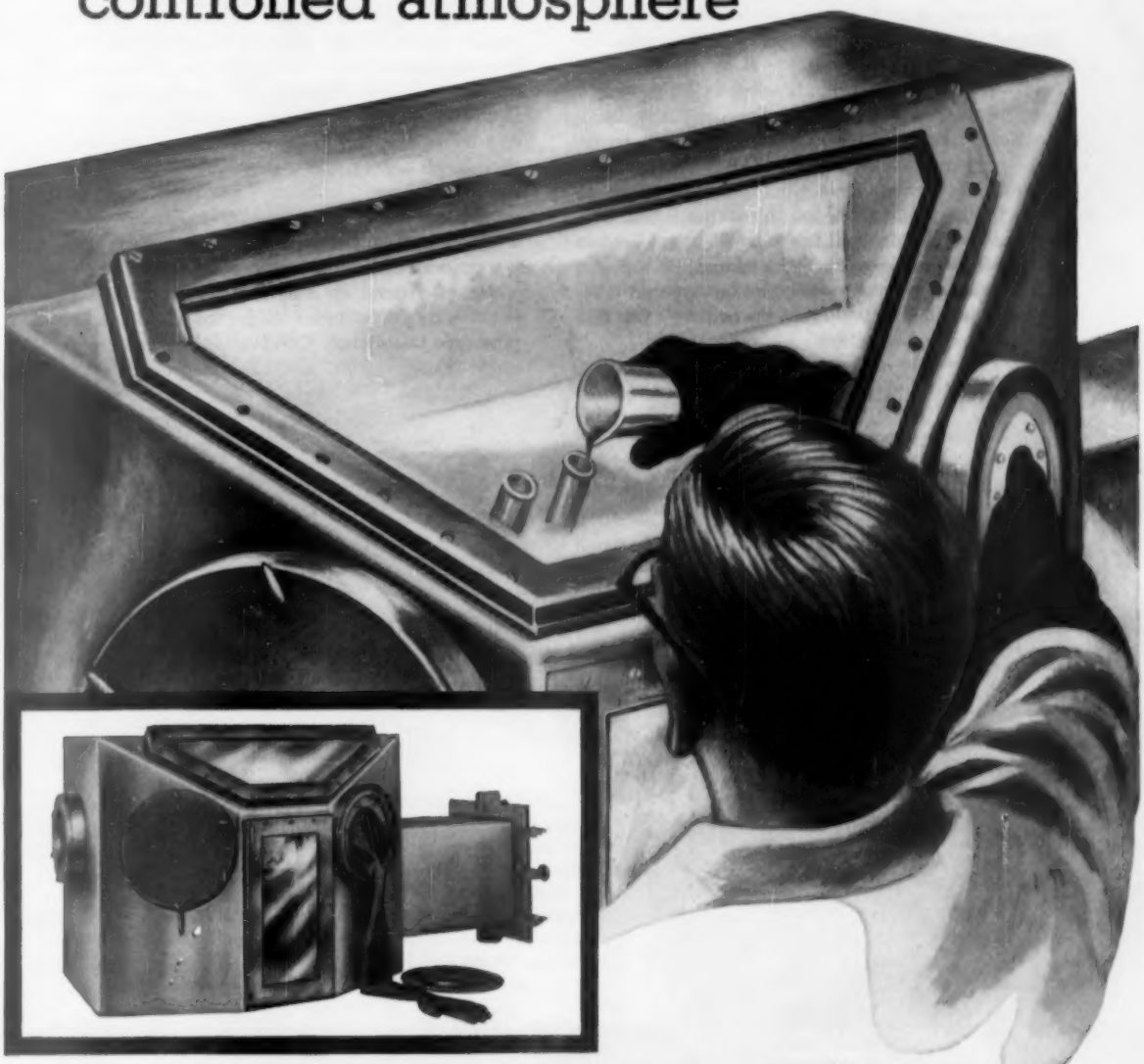
Chemical Reprocessing—I

Later Months—Chemical Reprocessing—II, III

Advanced Test Reactors

Sodium Reactor Experiment

designed for people who must work in a controlled atmosphere



BLICKMAN VACUUM DRY BOX

Designed by Blickman engineers for safe handling of radio-isotopes, reactor fuel containing Plutonium or U233 and other hazardous substances. Fabricated of stainless steel plate. With air-lock, it can be sealed to create a vacuum... then flushed to provide a controlled atmosphere. The vacuum dry box can be pumped to a 50 micron level. Leakage is less than 200 microns per hour. Dimensions overall are 34" long x 26" high x 24" wide at base. Air-lock measures 18" x 12".

Sturdy, all-welded construction assures long life ...rounded corners provide easy cleaning and decontamination. Send for Technical Bulletin A-2 or describe your specific problem. Write S. Blickman, Inc., 7903 Gregory Ave., Weehawken, N. J.

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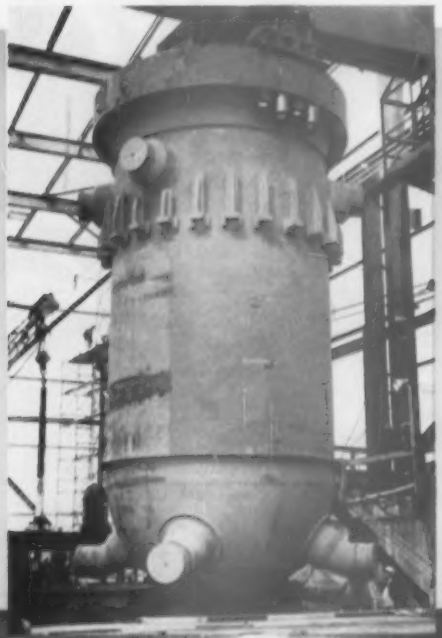
BLICKMAN

a decade of C-E nuclear progress

Combustion's activities in the nuclear field began in 1946 when studies were undertaken to determine the feasibility of power generation from nuclear fuels. Since then the Company has served as consultants and designers for the Atomic Energy Commission, the Navy Department and utility companies on reactor system components. It has designed and manufactured the reactor vessel, shield tanks and rotating plugs for the prototype of the submarine U.S.S. Seawolf and for the Seawolf itself; liquid metal heaters for the U.S. Navy Bureau of Ships and the U.S. Air Force; and the reactor vessel, end closure and internals for the Shippingport Plant, the country's first full-scale nuclear power plant.

Work currently in process includes the fabrication and assembly of five complete reactor cores for the U.S. Navy's nuclear submarine program; the reactor vessel, internals and rotating plugs for the Power Reactor Development Company's Fast Breeder Reactor (Enrico Fermi Station); the reactor vessels and steam generators for Submarine Advanced Reactor as well as reactor vessels, internals and closures for an aircraft carrier and a new type of ship called a frigate. To date, Combustion has done more heavy component work than any other company.

Most significant of the Company's present projects is a contract to design, develop, manufacture and test a nuclear reactor for a new type of submarine, and to serve as prime contractor for the construction of a prototype installation. Combustion was the first company to undertake a naval reactor project using its own facilities.

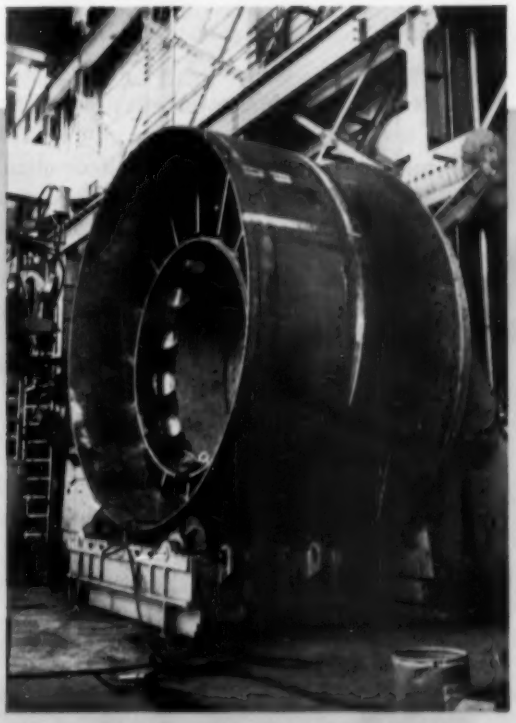


Heaviest unit of nuclear power equipment built to date—235-ton reactor vessel, designed and built by C-E, for country's first full-scale nuclear power plant. View shows vessel being installed at Shippingport Nuclear Power Station, Shippingport, Pa.

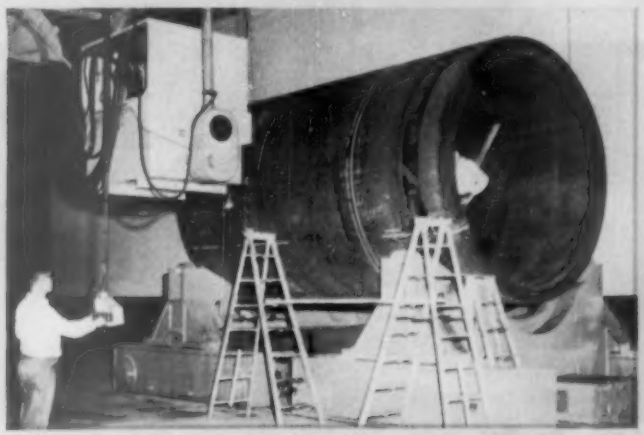
Aerial view of Combustion's Nuclear Power Division at Windsor, Conn., taken earlier this year when construction was nearing completion. This $15,000,000 plant is the largest privately owned facility of its kind constructed thus far. At lower right are the Critical Assembly Buildings. The three buildings in the upper left group are, from top to bottom, the Engineering and Administration Building, the Development Building housing chemical, metallurgical and physical testing laboratories, and the Fuel Element Fabrication Building. In another part of the 530-acre site, the prototype of a nuclear powered submarine is under construction.

Chattanooga Division, largest of Combustion's nine domestic manufacturing plants, is equipped with many special facilities for the manufacture of heavy nuclear components. These facilities are contained in the Nuclear Power Building (upper center), which is 535 ft long by 90 ft wide. Completed last year, this was the first facility in the country to be expressly designed and built for the manufacture of heavy nuclear components.

This IBM Computer System was the first installation of its kind anywhere. Located at C-E headquarters in New York, it is directly connected by transceivers to both Chattanooga and Windsor. Equipped with a "memory" in the form of a battery of magnetic tapes, it can "remember" literally millions of pieces of information and can be used to solve an almost endless variety of engineering problems. For example, it can solve an equation with 18 unknowns in a very few minutes.



Lower section of reactor vessel for Enrico Fermi Nuclear Power Station being built by Power Reactor Development Company. This highly complex vessel will be constructed of stainless steel throughout. It will be 37 ft high with a diameter of about 14 ft. It is shown here on the 50-ton welding positioner in the Nuclear Power Building at C-E's Chattanooga Division.



This 15,000,000-volt Betatron, installed in the Nuclear Power Building at the Chattanooga Division, is used for fast X-raying of extremely thick plate and welds. Here it is examining the 8½-inch thick wall of a reactor vessel.

COMBUSTION ENGINEERING

Combustion Engineering Building C-118

200 Madison Avenue, New York 16, N. Y.

all types of steam generating, fuel burning and related equipment; nuclear reactors; paper mill equipment; pulverizers; flash drying systems; pressure vessels; coil pipe

Announcing

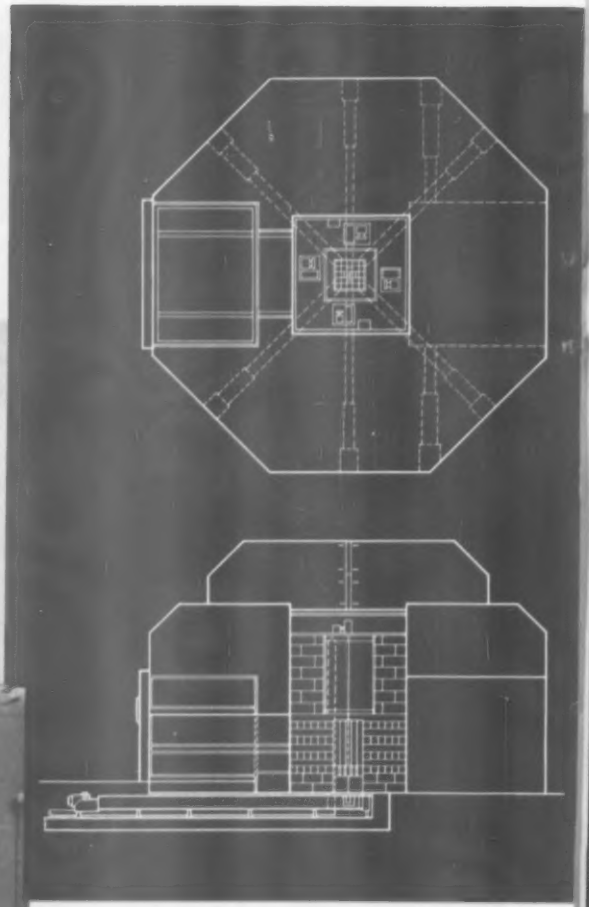
The Nucledyne

DESIGNED FOR TRAINING TESTING RESEARCH

The current "need to know" phase of peace time Nuclear Energy Applications requires a versatile, practical, and economical tool for the ultimate realization of economic nuclear propulsion and locomotion as well as the multitude of radiation applications requiring experimentation and study.

The present state of the art emphasizes the need for data which determine radiation damage affects, the constant improvement in energy conversion, the manufacture and use of isotopes and the training of skilled operators and technicians.

After carefully studying the reactors available, Nucledyne undertook the design of the NTR 100. This new reactor makes possible the following specifications and realizations.



NUCLEDYNE FURNISHES THE SUPPORT FACILITIES

The above operative 100,000 curie cobalt 60 hot cell was designed and constructed by Nucledyne. This cell will provide an area 16 x 16 x 15½ to be used for dynamic testing (under a 10^6 R/HR flux) to determine the effect of radiation upon fuels, lubricants and oils.

NTR 100 Reactor

This reactor design provides a basic neutron source that can be used by both industry and training centers. The use to which this design can be put is limited only by the imagination of the user. For a minimum cost, a medium flux level of 10^{12}n/cn^2/sec. is achieved. This enables the researchers in reactor engineering, chemistry, physics, biology, and medicine to explore the peace time uses of the atom.

Because of the flux level and "customized" experimental facilities this reactor can be used in most testing situations.

Typical experiments used in reactor engineering training can be performed with ease and safety. Start up and operating procedures are those in common use on most reactors providing thorough training in reactor operation.

REACTOR CORE

The reactor core uses a standard and well proven type of fuel element; namely the MTR type fuel plates. The core is water moderated, water reflected top and bottom, and graphite reflected on the sides to achieve a high flux to power ratio by lowering the critical mass.

REACTOR SHIELD

The biological shield is barytes concrete. Experimental facilities such as water irradiation tank, thermal column, beam holes, etc. can be designed to meet individual requirements.

CONTROL ROD SYSTEM

Four symmetrically located control rods are being used. One is under servo control, one is a shim and the other two are cocked for safety rods.

SHUTDOWN MECHANISMS AND SAFETY FEATURES

The reactor core has large negative temperature and void coefficients plus two independent shutdown mechanisms. These shutdown mechanisms consist of insertion of gravity actuated rods and a moderator dump feature.

GENERAL REACTOR DESCRIPTION

Maximum Power:	100 kw
Maximum Thermal Flux:	$>10^{12}$n/cm^2/sec
Critical Mass:	2.5 kg
Type of Core:	Four side graphite reflected heterogeneous, water reflected top & bottom
Core Size:	5 element x 5 element, MTR type
Available Test Area on One Face of Graphite Reflector:	5 ft.^{2}
Graphite Thermal Column:	5ft. x 5 ft. x 6 ft. deep
Moderator & Coolant:	Water
Over-all Reactor Height:	11 ft.
Maximum Width (across corners of octagon)	18 ft.
Biological Shield:	6 ft. Barytes Concrete
Shield Over Lattice:	3.5 ft. Water and 3.75 ft. Barytes Concrete
Water Circulation Rate:	34 gpm
Storage Tank Volume:	500 gal.
Power Requirements:	50 kw, 110-V a-c, Single Phase

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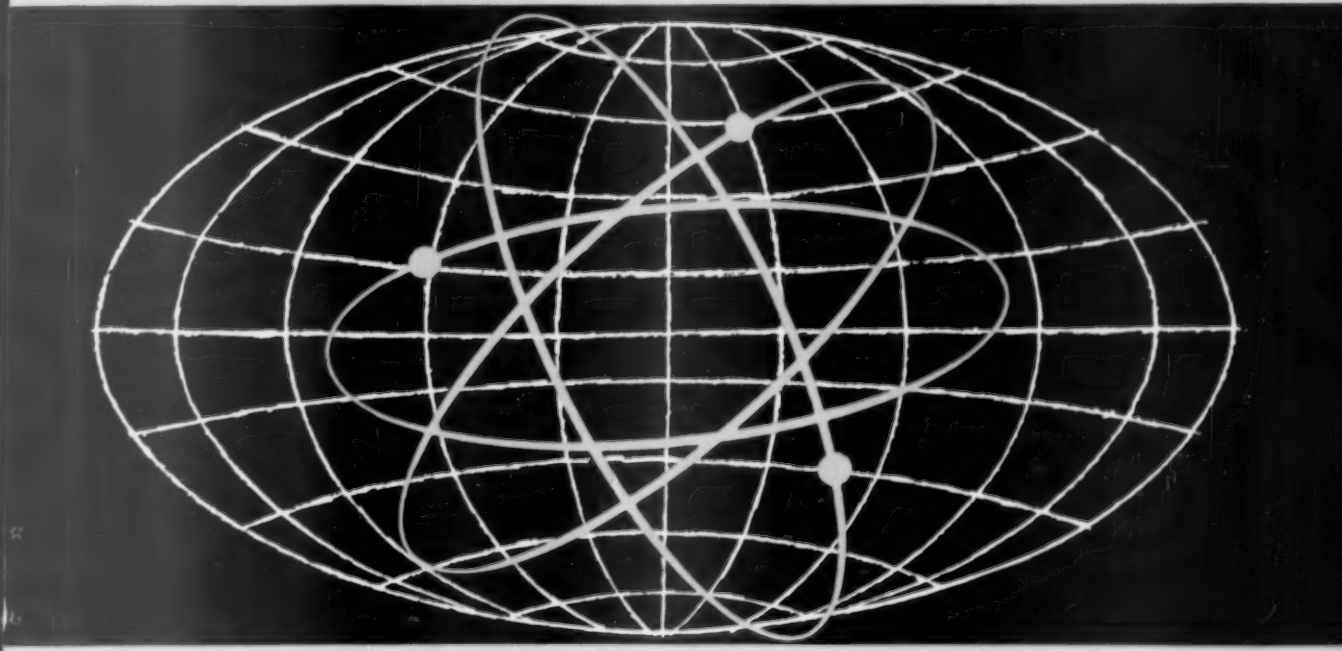

...WITH BORG-WARNER

In the challenging world of nucleonics, Borg-Warner engineering skills and production experience are today contributing to important technological advances.

Especially noteworthy among recent B-W nuclear developments are a new liquid sodium pump for primary cooling . . . control rod drive mechanisms for use in nuclear powered electric generating plants . . . a highly refined electro-mechanical manipulator for fully-remote handling of radioactive materials . . . a new automatic Gamma ray spectrum recorder . . . and other advanced radiation counting and measuring instruments.

In Borg-Warner's extensive new Research Center, keen scientific minds are now at work probing the nuclear unknown to further the continuing Borg-Warner tradition: "Design it better —make it better."

On the following pages you'll see some of Borg-Warner's contributions to nucleonics. Just beyond the horizon are more to come.

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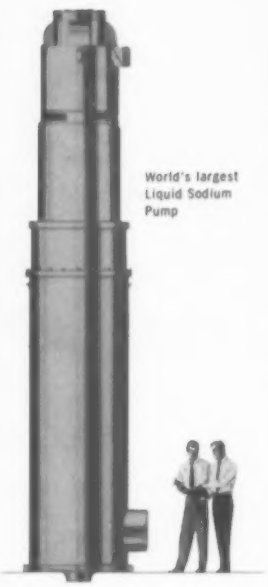
A simplified guide to select...

pumps for nuclear fluids!

The chart below offers an easy guide to proven pump types now available for nuclear fluid handling. These pumps are listed by types of fluid circulated in the three basic commercial reactor developments.

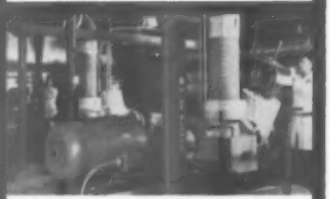
BJ Liner Motor Pump

	FLUID CIRCULATED	RECOMMENDED PUMPS AVAILABLE	PERFORMANCE RANGES
1	PRESSURIZED WATER, BOILING WATER AND HEAVY WATER	a. Liner Motor Pumps	Capacities: To 17,000 gpm Pressures: To 5300 psi Temperatures: To 700° F.
		b. Mechanically-Sealed Pumps	Capacities: To 125,000 gpm Pressures: To 2,000 psi Temperatures: To 600° F.
2	LIQUID METALS (SODIUM, BISMUTH, ETC.)	a. Vertical-Inert Gas (Mechanically-Sealed)	Capacities: To 25,000 gpm *Pressures: Temperatures: To 1600° F.
		b. Vertical-Oil Filled Motor Pump (Mechanically-Sealed)	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
		c. Vertical-Gas Filled Motor Pump	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
	*Pressures as required	d. Liner Motor Pumps	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
3	ORGANIC	a. Special Process Pumps (Mechanically-Sealed)	Capacities, pressures and temperatures as required.
4	EXPERIMENTAL NUCLEAR DEVELOPMENTS	Byron Jackson's Nuclear Pump Section is ready to assist you in new development projects. All of the above pump types are available and new designs can be created for experimentation.	Capacities, pressures and temperatures as required.



World's largest Liquid Sodium Pump

ONLY BYRON JACKSON designs and manufactures nuclear pumps and mechanical shaft seals to answer all nuclear fluid handling requirements. BJ Pumps are in use or on order for almost all major commercial reactor developments in the United States. This broad background in nuclear pumping methods can help you find the best answer to your small or large nuclear pumping requirements... with important savings in time and money.



BJ Special Process Pump for Organic Fluids

BJ
SINCE 1872

BYRON JACKSON PUMPS
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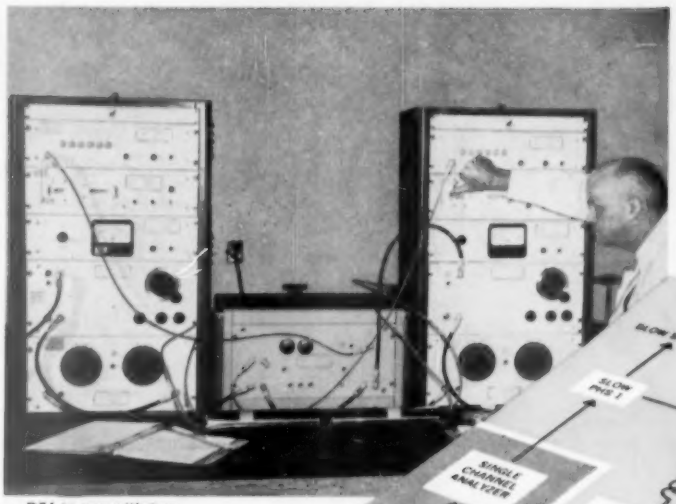
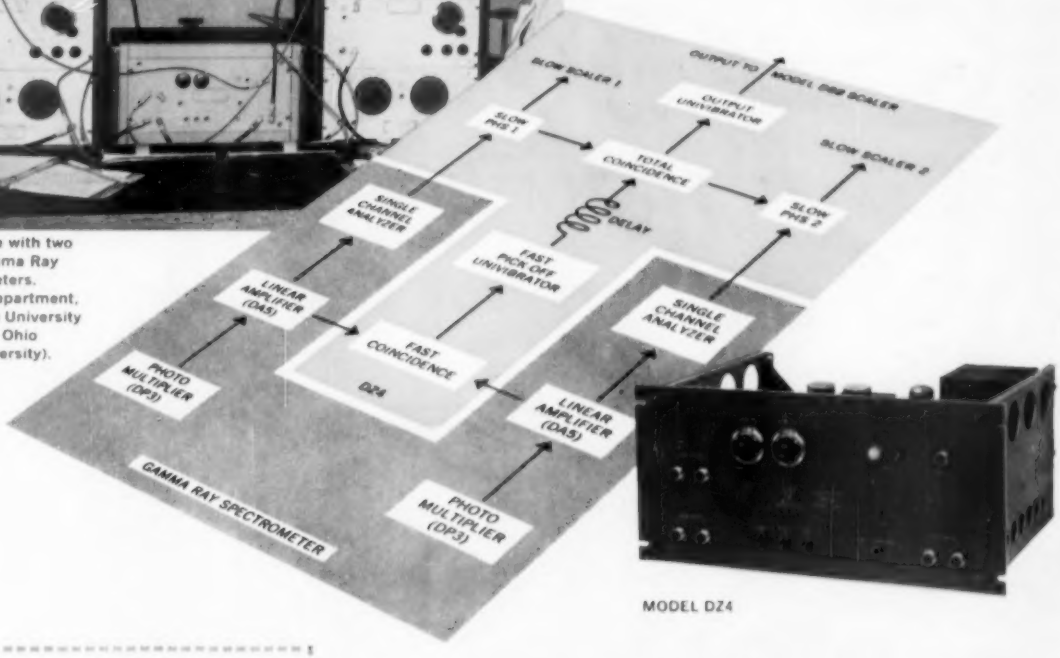
¼ HP, 2000 PSI Liner Motor Pump

For the Field of Advanced Nuclear Research —these Detectolab® Products



DZ4 in use with two DZ41 Gamma Ray Spectrometers. Physics Department, Ohio State University (Courtesy, Ohio State University).



MODEL DZ4

Linear Count Rate Meter

Model DM12 is a high precision laboratory instrument designed to count pulses from GM tubes, scintillation detectors, single channel pulse height analyzers and the like. Identical to the ORNL Q-1511 circuit, this model features:

- Better than 1% accuracy.
- Long term stability better than 2%
- Front panel control of input sensitivity, continuously variable from −50 to +100 volts.
- Ten counting ranges to 3,000,000 cpm.
- Provisions to drive 0-10 millivolt recorder.
- Front panel calibration control.
- 2.0, 0.6, 0.2% standard deviation control.

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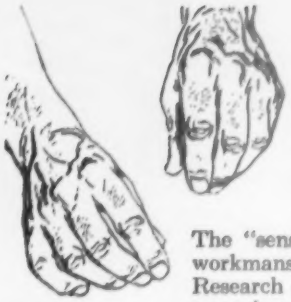

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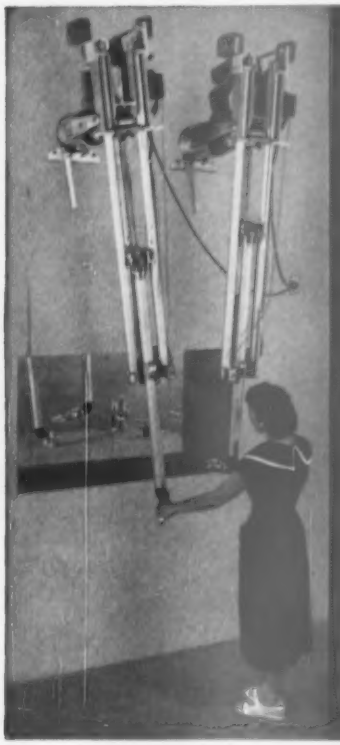

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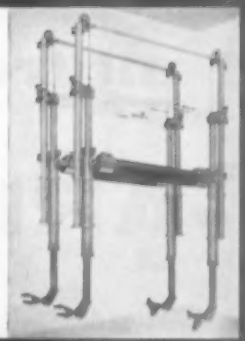

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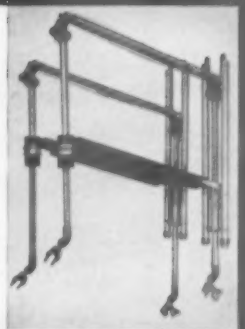

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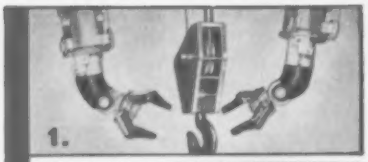

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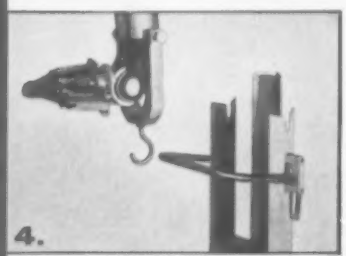

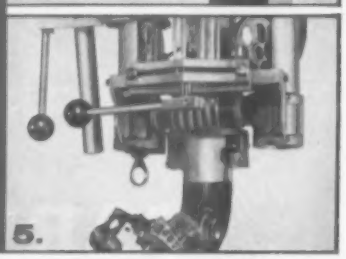

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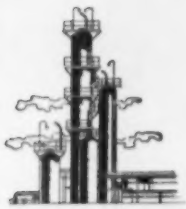

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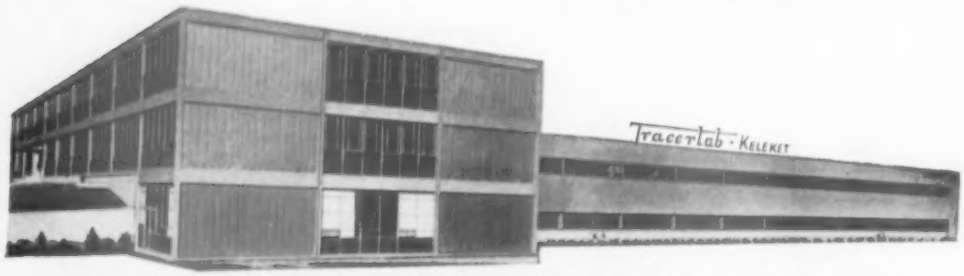

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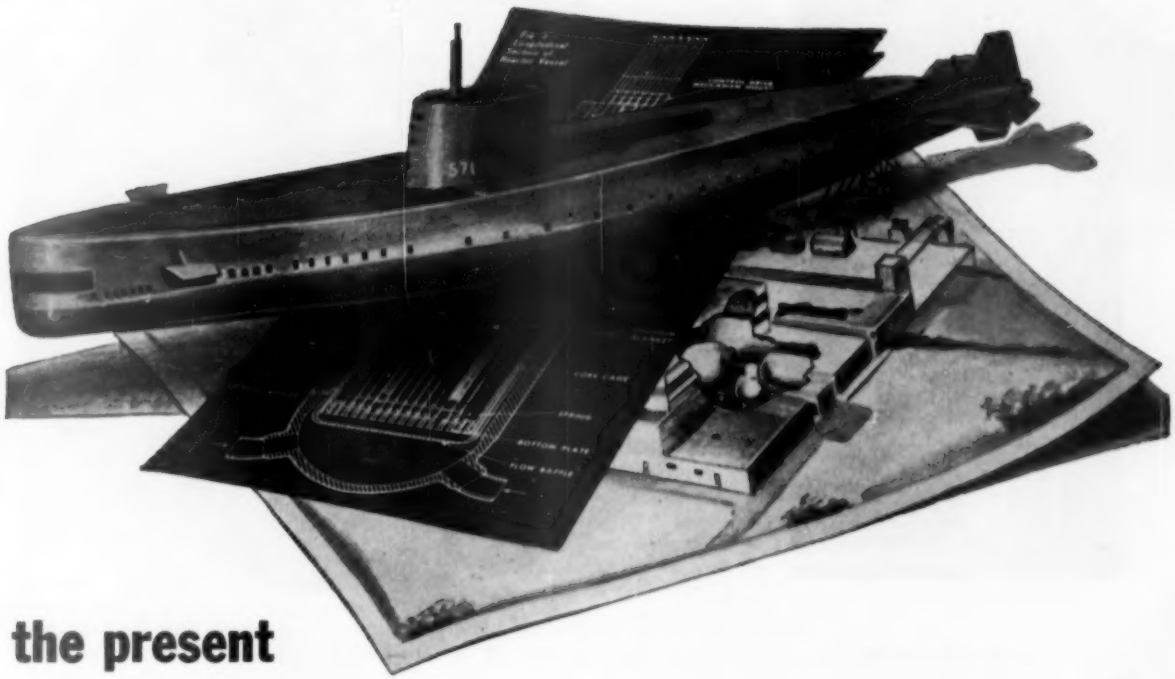

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To complement these facilities, NDA-Europe has been formed with leading Belgian industrial firms to combine American nuclear experience with Europe's well-established manufacturing facilities in carrying out atomic energy business in the Euratom countries and their colonies, possessions and territories.

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ROUNDUP of Key Developments in Atomic Energy

Congress Passes Broadened 1958 Reactor Program

The nation finally got an atomic energy program last month for the new fiscal year, already one-sixth past.

It was a hectic month on Capitol Hill, one that left the industry gasping in confusion trying to keep up with the moves and countermoves of the Congressional bodies concerned. It seemed almost as though there were not two views, a majority and a minority, on what the program should be, but 531 (the number of members of Congress); the Joint Committee on Atomic Energy, its subcommittee on authorizing legislation, the House Appropriations Committee, the Senate Appropriations Committee, and the full House and Senate all took turns rewriting the program.

The one that finally emerged, carrying a $2,323,632,00 appropriation, gave AEC virtually all it had asked for in its budget requests—and more: for Congress forced on AEC three reactor projects, two of which AEC itself had strongly advised against. However these projects were finally passed in a compromise form much less sweeping than first proposed. Nevertheless the gulf that opened up this year between AEC and JCAE yawned even wider than before. Many observers feel the relationship between the two bodies has deteriorated to perhaps the lowest point in their history; some go further and point to the friction between personalities as the underlying reason for many of AEC's current legislative difficulties.

Other Actions

In three other long-awaited actions, Congress finally:

- passed the government indemnity bill that provides for U. S. underwriting of nuclear reactor risks over and above the $65-million top private coverage to a maximum of $500-million per risk (NU, May '57, 18; July, 17);
- confirmed John F. Floberg, and John S. Graham (NU, July '57, 17) as members of the Atomic Energy Commission, restoring AEC to its full membership of five for the first time since the death in February of John von Neumann;
- passed a bill providing for U. S. participation in the International Atomic Energy Agency, but with a watered-down version of the Bricker amendment. This now provides that Congressional approval is required for all allocations of fissionable material by the U. S. to the Agency (excluding offers already made: 5,000 kg U^{235}, plus an amount matching the offers of all other member countries up to July 1, 1960).

The New Program

Here is the action taken in Congress on the controversial features of the fiscal 1958 reactor program:

Small co-ops. Four of the five proposals by rural electric cooperatives to build nuclear power stations—on which AEC and the co-ops have been negotiating fruitlessly for more than a year—will be taken over by AEC under the Duquesne-Shippingport formula (NU, Aug. '57, 18): Piqua, Elk River, Wolverine and Chugach will be built and owned by AEC; the Commission will negotiate directly with the equipment manufacturer (respectively Atomics International, AMF Atomics, Foster Wheeler, and Nuclear Development Corp. of America) regarding development, design and construction, but directly with the utility concerned regarding the site, the turbogenerating facilities, operation of the reactor, training of personnel, and sale of steam. This last is to be at rates "based upon the present cost of, or the projected cost of, comparable steam from a plant using conventional fuels at such locations." The new law carries $48.2 million for these plants. It also provides that these four projects shall be operated under contract with AEC "for such period of time as the Commission

Vallecitos Boiling Reactor Critical

The nation's first privately-financed power reactor to be completed—General Electric's 5-Mw (electric) pilot boiling water plant at Vallecitos, Calif. (NU, July '57, 57)—achieved criticality Aug. 5. At month's end the reactor was issued AEC's developmental power reactor license No. 1. Criticality came during low-power experiments to determine core characteristics; full-power operation and steam production will not start until sometime this fall. The steam will be fed to a turbogenerator installed adjoining the reactor by Pacific Gas & Electric Co., which will distribute over its grid the current made. The reactor will serve as prototype for the 180-Mw Dresden boiling water power reactor GE is building near Chicago for Commonwealth Edison.

Vallecitos made news on two other occasions last month. First, GE announced award of a design and construction contract to Ralph M. Parsons Co. for facilities to house GETR—GE's $4-million materials testing reactor for Vallecitos (NU, June '57, 26). The reactor itself will be designed and built by GE. Four main structures are involved in the Parsons contract: a 66-ft-dia, 104-ft-high steel containment vessel to house the reactor and irradiation facilities; a control and office building; an equipment and shop building, and a water cooling tower. AEC has been asked for a construction permit, and preliminary site work is to start soon.

Second, AEC issued GE an operating license for another experiment facility containing a critical assembly and a low-power reactor (NTR) for producing neutrons; an application for a construction permit covering the latter reactor is pending before AEC. First critical experiments to be performed are on low-enrichment uranium dioxide fuel rods in a tank of water—to measure nuclear characteristics of the Dresden reactor core.

determines to be advisable for research and development purposes but in no event to exceed ten years"; after that period, AEC must offer the reactor for sale to the operating co-op "at a price to reflect appropriate depreciation but not to include construction costs assignable to research and development." If the coop "elects not to purchase the reactor and its appurtenances, the Commission shall dismantle them."

Nebraska. The fifth co-op proposal, however—the Consumers Public Power District of Columbus, Neb., plan for a 75-Mw sodium-graphite reactor—was left out of the new formula in a compromise move. CPPD thus would remain the prime contractor, and would deal with the reactor builder, Atomics International. $50.1-million is authorized for this—a much larger reactor than the other four, which range from 10 to 22 Mw.

Detroit fast breeder. The research and development aid for Power Reactor Development Co.'s Fermi fast breeder reactor at Lagoona Beach near Detroit, at one point written entirely out of the appropriation bill, was restored prior to passage, but only in the amount of $1.5-million instead of the $4.2-million asked by AEC. However JCAE members said the $1.5-million was all that AEC had asked for fiscal '58, the $4.2-million being the total required over the next three years for the project; they asserted the cut was not a reduction of the aid AEC could give PRDC.

Third round. $30-million was provided for AEC aid to industrial projects under the third round of the Power Demonstration Reactor Program.

Pu recycle. $5-million was voted to start work on PuRR—the Hanford plutonium recycle reactor. JCAE had originally voted to authorize the entire $15-million estimated cost of the facility, although AEC had contended the money was being voted one year prematurely. The House, much more sensitive to the Administration's wishes, eliminated the authorization, and the Senate restored it. On the actual appropriation bill, a compromise $5-million was fixed on to get the project under way.

Dual-purpose. For a dual-purpose production-and-power reactor, which AEC opposed, $3-million was voted "for development, design and engineering only." The new law provides that AEC "shall proceed with sufficient design work, together with the appropriate engineering and development work, necessary for AEC to begin construction as soon as practicable after authorization by the Congress, of a large-scale single or dual purpose reactor for the production of special nuclear materials [plutonium *Ed.*]. AEC shall submit to JCAE a report on its design for this project, including cost estimates and schedule of construction, not later than April 1, 1958."

Gas Cooled Reactor Experience Available to Design Unit Congress Asked

Reactor	*Engineering Firm*	*Customer*	*Thermal Power (Mw)*	*Fuel Enrichment*	*Max. Gas Temp. (°F)*	*System Press. (psi)*	*Gas*	*Fuel Element*		*Moderator*	*Cycle*	*Critical Date*
								Meat	*Clad*			
Daniels Pile	ORNL	AEC	12	30%	1400	150	He	UO_2-BeO	None	BeO	Steam	1948
Calder Hall	4 British consortia	Central Elec. Auth.	182	natural	637	100	CO_2	U	Mg	Graphite	Steam turb.	1956
Hunterston, Scotland	GEC–Simon Carves	South of Scotland Elec. Board	530	natural	745	150	CO_2	U	Mg	Graphite	Steam turb.	1960
Florida Power	General Nuc. Eng.	Florida Power Group	680	natural	670	500	CO_2	U	Zr	D_2O	Steam turb.	Under negotiation
Gas Cooled* Reactor Exp	Aerojet Gen. Corp.	AEC	classified	highly enriched	>1000	several hundred	N_2	UO_2-SS	SS	Classified	Heat dumped	1959
Merchant ship study	General Atomic	Maritime Admin.	55	30%	1300	2000	CO_2	UO_2-SS	SS	ZrH	Direct, gas turb.	——
Merchant ship study	General Motors	Maritime Admin.	55	fully enriched	1300	1000	He	UO_2-SS	SS	Graphite	Direct, gas turb.	——
Merchant ship study	Ford Instrument	Maritime Admin.	65	5%	1150	600	He	UO_2	SS	Graphite	Direct, gas turb.	——

* Part of joint AEC-Army program to develop direct-cycle gas-cooled portable power reactor (NU, Nov. '56, R 6; Sept. '57, 30).

The first known work on gas-cooled power reactors was also the U. S.' first A-power project: the Daniels pile at Oak Ridge in 1946. This project was dropped because of major technical problems combined with insufficient economic incentive.

Now, 11 years later, the U. S. has come full circle, embarking on a substantial gas-cooled reactor effort. Apart from any intrinsic virtues that such reactors might have, the success of the British with their Calder Hall plant has played a major role in pushing the U. S. down this new technological route.

As can be seen from the table, the new gas-cooled designs can conveniently be separated into two groups—those that use a direct-cycle gas turbine, and those that use a secondary coolant loop to drive a steam turbine, as in Calder Hall. The former group calls for expensive and exotic core materials and operating conditions far beyond today's engineering. Whether or not the higher efficiency of a direct-cycle commercial power reactor can outweigh these disadvantages will be answered in the future. The second group of reactors—those that have steam turbines—are the reactors of today. They represent more modest extrapolations of Calder Hall engineering experience. To this extent, their economic advantages over Calder Hall are also likely to be modest. The Florida Power Group reactor probably represents the best that can be done in the U. S. with the first generation of gas-cooled reactors using the steam cycle. Its energy cost is expected to be in the neighborhood of 12 mills/kwh.

Calder-type. Finally, the project AEC and Administration supporters in Congress opposed most vigorously as being unnecessary, a diversion of effort into unrewarding channels, and misleading abroad—an American Calder-type natural uranium, graphite - moderated, gas - cooled power reactor (*see table p. 22*)—was voted. But where the original JCAE authorization bill would have voted $40-million for construction of such a reactor at AEC's reactor testing station in Idaho, the law as passed carries only $3-million for preliminary development, design and engineering. As in the case of the dual-purpose reactor, AEC is enjoined to do "sufficient" design, development and engineering to be able to start construction as soon as that is authorized by Congress, and to report to JCAE by April 1.

Also restored after having been deleted at one point were $11-million for physical research and $3-million for biology and medicine.

Passage of the money bill came none too soon, for with almost two whole months of the 1958 fiscal year elapsed since July 1, some AEC field offices were already finding it a problem to meet payrolls.

Background for Congressional Action

To understand the tortuous convolutions in the legislative history of the fiscal 1958 atomic budget, it must be borne in mind that the 1954 Atomic Energy Act requires (Sec. 261) that a bill to *authorize* expenditures for acquisition of real property or for plant or facility acquisition, construction or expansion must be signed into law before Congress may *appropriate* such capital funds. Hence for new reactor projects, not one but two bills must be passed: an authorization bill, originating in JCAE (or, more precisely, in JCAE's subcommittee on authorizing legislation); and an appropriation bill, originating in the House Appropriations Committee's subcommittee on public works. This is why this year the atomic budget measure, being controversial, had ten versions, as first the authorization bill was drafted and redrafted in JCAE subcommittee, the full JCAE, on the House floor, on the Senate floor, and finally in a House-Senate conference committee to reconcile the differences in the two bodies' versions; and then the appropriation bill wound its way up through similar channels.

Opinion in JCAE

Leading members of JCAE of differing persuasions all expressed themselves as being highly satisfied with the compromises wrought in conference committee.

Chairman Carl T. Durham (D-N. C.) said he felt the conferees "did a very good job; everybody is pretty well satisfied, as far as I know." He pointed out that AEC was the only government agency to get more money this year than it did last—no mean trick in an economy-drive year.

Former chairman and ranking minority member W. Sterling Cole R.-N. Y.) told NUCLEONICS he considered it "a remarkably successful conference—all the more when you realize the controversy had been going on for two months, and in two hours the conference resolved it with no acrimony, calmly and soberly, and left all the conferees reasonably satisfied."

On the Calder-type project, Cole said that with only preliminary work now called for, two equally-valid interpretations abroad were possible: either that the U. S. thinks so well of this British reactor that it feels impelled to adopt the type as one of its own, or else that the U. S. has such doubts about it that it needs to investigate and verify them itself. The former interpretation is the one AEC had said earlier would gain currency abroad if immediate construction of the $40-million, 40-Mw gas-cooled reactor were voted (and certainly word from England is that glee reigned at the British Atomic Energy Authority the day the project was drafted into the authorization bill).

AEC spokesmen are saying not without bitterness that although the British have not yet closed a single deal for export of a Calder-type power reactor, they will probably sell several now with the aid of what they will represent as U. S. endorsement of the type. On the other hand, Rep. Melvin Price (D-Ill.), chairman of JCAE's research and development subcommittee, says this argument is the weakest one AEC leveled against the project; he, with several fellow-Democrats, contends the Calder type has been so successful in Britain that the U. S. cannot afford not to master its technology. Moreover, they point out, this reactor is desirable for export because of its appeal to countries that do not wish to rely on the U. S. as sole source of enriched uranium. Price thinks U. S. industry could compete in the world market over the long haul in supplying components for Calder-type reactors. Other AEC arguments against the type are that its capital cost is too high; that it is out of date, with even the British going to slightly-enriched uranium fuel for their all-power stations; and that the heavy-water-moderated reactor—which Walter H. Zinn is developing for the Florida Nuclear Group—is a better application of natural uranium fuel.

AEC will invite leading architect-engineers in the nuclear field to bid on making the design study required by April 1. In addition, it is suggesting that those interested in building the plant—should Congress order this next year—team up now with an equipment manufacturer.

As regards the four small co-operatives, the vote to require AEC to assume direct control of construction was a victory—if on a small scale—for the Democrats who have been trying (as with the Gore bill last year) to have the Government undertake power reactor building projects to hasten development. Conversely the proviso that after ten years AEC must sell or demolish was a victory for the Republicans, determined to keep the Government from getting into the atomic power business. This clause "makes it clear," Cole told NUCLEONICS, "that no precedent is set; the Government gets out after the research and development phase. It definitely, positively takes the Government out of using atomic energy to generate electricity over a period of time."

The Joint Committee and AEC have been at odds over how to handle the co-op program: the co-ops have no risk capital, and whatever formula may be drafted it will be the Government that will have to foot the preponderant part of the bill. However JCAE feels the co-ops don't know enough about the atomic power business to warrant their being made responsible for construction as well as operation; it wants AEC to build the plants and turn them over to the co-ops to operate. AEC contends the co-ops must learn the business and can learn best by doing. Underlying all this is the age-old political situa-

tion: the Republican Administration contends the Democratic-controlled Congress is really trying to get the Government into the atomic power business, while the Administration is determined to keep it out.

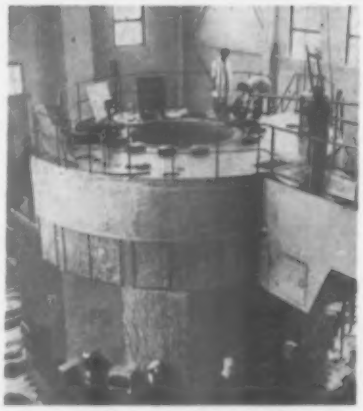
The fuel restriction clause in the International Agency participation act also was softened in a last-minute conference compromise. Instead of singling out the Agency as the only recipient of AEC allocations of fissionable material for which prior Congressional approval must be sought, the provision now states that "the Agency, or any group of nations" is so bound, thus allegedly removing the discrimination against the Agency. Another change inserts the words "and for such periods of time" into the provision, "AEC may distribute to IAEA, or to any group of nations, only such amounts of special nuclear materials and for such periods of time as are authorized by Congress. . . " The intended implication is that long-term or continuing allocations may eventually be made. AEC is still unhappy over the softened restriction, but JCAE members in reply point an angry finger at Francis Wilcox, Assistant Secretary of State, who, they say, "pulled the rug out from under us." After the Bricker restriction had first been adopted by JCAE, the State Department asked the Committee to be heard in a plea for reconsideration; but, fearing that the restriction might be adopted anyway and that it would look worse abroad if the Administration were rebuffed, Wilcox told JCAE that "we can live with it" [the Bricker amendment]. How excessively pessimistic this move was, was shown when the House knocked out the Bricker amendment. The Senate, heeding both Bricker and Wilcox, put it back in.

The Detroit fast breeder situation was complicated by the argument that has raged all year over its safety. Some on JCAE wanted the money to go for fast breeder research in general, rather than to PRDC, pending establishment of the PRDC reactor's indubitable safety. As it now stands, $13.6-million has been voted for work on AEC's first and second experimental breeder reactors at the Idaho testing station—over and above the $1.5-million available to PRDC. However the narrow escape from deletion of the $1.5-million for PRDC may still give private firms some second thoughts about entering into partnership arrangement with the Government.

As to the dual purpose reactor, behind it lies the conviction of some in Congress, including JCAE chairman Durham, that the U. S. should expand its plutonium production

(*Continued next column*)

Research reactors for Europe—East and West



(Above) Aerial view of Riso peninsula in Denmark 20 mi W of Copenhagen, where Danes' first reactor—an Atomics International 5-watt solution-type unit (A)—has been placed in operation. The 5-Mw tank-type Foster Wheeler research unit is building at (B). Rumania's 2-kw Soviet-supplied research reactor (lower right) began operating July 31. It is presumed to be identical to that supplied Czechoslovakia (sectional sketch NU, April '56, 19) which started operating July 8, and the one at Swierk, Poland, (lower left), now 40% assembled. Hungary and Bulgaria are also getting this model, which uses 10% enriched uranium fuel and light water for moderation and cooling

Five New U. S. Bilaterals; 21,350 kg U-235 Allocated

Five new bilateral agreements for cooperation in the field of nuclear power became effective last month, and a sixth was signed and laid before Congress to fulfill the required 30-day waiting period. Italy, West Germany, Brazil, Peru, and the Union of South Africa were allocated a total of 11,350 kg of U^{235}, with Italy getting the lion's share, 7,000 (*see p. 28*). Spain will get 500 kg when its bilateral becomes effective next January or February.

The five new effective bilaterals bring to 13 the number of nations having power pacts with the U. S. (NU, Nov. '56, 67; April '57, 26). A total of more than 16,314 kg U^{235} will be furnished these countries (see Table 1); this figure does not include the amounts to be furnished under open-end agreements, nor the 5,000 allocated to the International Atomic Energy Agency. In addition, 28 (of 33) research bilaterals call for distribution of 216 kg of U^{235}. Amounts already shipped from the U. S. are shown in Table 2.

(*Continued from previous page*)

capacity. The Joint Committee noted that "AEC in establishing the $30/gm price for plutonium is apparently recognizing a greater need for this material for weapons purposes." It is intended by JCAE that AEC in selecting the type of plutonium-producing reactor for design would choose either (a) a dual purpose reactor maximizing plutonium production with electric power production as a secondary by-product, or (b) a single-purpose reactor for maximum plutonium production. The determination would be based upon a consideration of which type would produce the lowest cost plutonium to the Government, and which would provide for the greatest advance in reactor technology.

Passage of the indemnity bill removes what industry had long pointed to as a major hurdle to private development of nuclear power. General Electric vice president Francis K. McCune had told Congress that his firm would have to cease work on the Dresden reactor station for Commonwealth Edison near Chicago if the bill failed to pass again this year.

TABLE 1—U. S. Uranium Allocations Abroad

Research Reactors:	
Argentina	6 kg*
Austria	6
Brazil†	6
Chile	6
(Nationalist) China	6
Colombia	6
Cuba	6
Denmark†	12
Dominican Republic	6
(West) Germany†	[12]‡
West Berlin	6
Ecuador	6
Greece	6
Guatemala	6
Iraq	6
Ireland§	6
Israel	6
Italy	[6]‡
Japan†	6
(South) Korea	6
Lebanon	6
Netherlands†	[6]‡
New Zealand	6
Nicaragua	6
Pakistan	6
Peru	[6]‡
Philippines	6
Portugal	6
Spain	[6]‡
Sweden	12
Turkey	6
Uruguay	6
Venezuela	6
Power Reactors:	
Australia	500
Belgium	open end†
Brazil	350
Canada	open end†
France	2,500
(West) Germany	2,500
Italy	7,000
Netherlands	500
Norway	500
Peru	800
Spain¶	500
Switzerland	500†
Union of South Africa	500
United Kingdom	0
Int'l Agency	5,000

* Total commitment for 6 or 12 kg is increased, for research reactor bilaterals, by a factor of three to cover "pipeline" requirements—i.e., uranium needed for fuel elements in transit and being reprocessed, sufficient to keep reactor in operation. For power reactor bilaterals, figures shown include pipeline allowance.

† Have already received shipment from U. S.; see Table 2.

‡ Except in the case of Brazil, power bilaterals supersede research agreements, with the total commitment being contained in the former.

§ Not yet ratified by Irish government.

¶ Now before Congress to fulfill required 30-day waiting period.

TABLE 2—Enriched Uranium Already Shipped from U. S.

Destination	*Date shipped (all 1957)*	*Amount* ($kg\ U^{235}$)	(*kg U*)	*Form*
Belgium	6/9			30 lb of highly-irradiated slugs
	6/14	0.45	0.5	one metal button
Brazil (Sao Paolo)	8/3	5.9	29.99	40 fuel elements
Canada (Pool Test)	6/26	5.72	6.14	42 fuel elements
(Pool Test)	7/23	0.63	0.68	4½ fuel elements
(NPD study	3/27	3.33	16.73	uranium dioxide
Denmark (Risø)	5/31	1.40		11.35 kg $UO_2SO_4 \cdot 3H_2O$ solution
	5/31	0.0003	0.0017	one fission counter
	7/16*			1 gm UF_4, fine powder
	7/16	0.00322		U_3O_8
Germany (Frankfurt)	7/23	1.80		14.58 kg $UO_2SO_4 \cdot 3H_2O$ solution
	7/23	0.00069		U_3O_8 in two fission counters
(Munich)	8/29	5.75	29.94	28 standard, 9 control, 2 partial fuel elements
Japan (JAERI)	5/24	1.98		17.75 kg $UO_2SO_4 \cdot 3H_2O$ solution
	5/24	0.0006		3.1 gm U_3O_8 in two fission counters
Netherlands (Exhibit pool)	2/18	0.62	3.2	7 control rods
	4/9	4.07	20.73	22 fuel, 2 partial fuel elements
	4/9	0.00069		2.9 gm U_3O_8 in two fission counters
Switzerland (Exhibit pool)	8/22†	5.87	30.60	fuel elements

* Exploratory logger for U prospecting in Greenland.

† Date of transfer (after Geneva conference).

Cole May Head Agency; First Year's Program Set

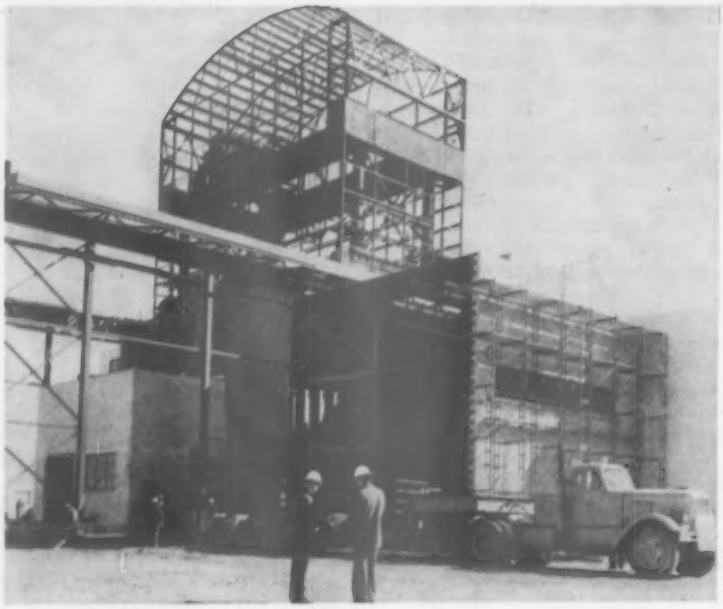
Congressman W. Sterling Cole, ranking minority member of the Joint Committee on Atomic Energy and former JCAE chairman, took a long lead on the job of first director-general of the International Atomic Energy Agency when Russia let it be known she would not oppose selection of an American for the post. The New York Republican told NUCLEONICS that although loath to leave Congress (he is serving his twelfth term), he feels duty-bound to accept the job if it is offered. The director-general is chosen by IAEA's Board of Governors.

Meanwhile a rather modest program for the Agency's first year was drawn up by its Preparatory Commission and published on the eve of the new organization's first General Conference, to open Oct. 1 in Vienna. This recommends that during its early years, because of the widespread shortage of trained personnel, IAEA concentrate on assisting member states to plan research programs or develop existing ones, to develop and apply research techniques, provide technical advice and help disseminate information.

"It is widely expected," the program states, "that in the long run the development of . . . power reactors will be the most important . . . and extensive of [IAEA's] activities . . . There are, however, important limitations to the initial scope of the Agency's reactor program," because nuclear power will first be competitive in a few highly-industrialized member countries, and because "the Agency cannot itself finance reactor projects, and the outside sources of finance at the disposal of its members are limited. The Agency's reactor program must reflect a balance between these technical and economic factors . . . The Agency's initial activities will consist largely of surveys, provision of technical advice, exchange of information, evaluation and longer-term planning." In addition, a "special reactor program" is contemplated, of building "a small number of medium-size reactors . . . with a view to giving the maximum benefit to the largest possible number of members."

The report recommends the secretariat staff of about 370 be divided into these substantive divisions: economic and technical assistance; inspection; research, research contracts and laboratories; isotopes; reactors; scientific and technical information; exchange and training of scientists and experts; safeguards; health, safety and waste disposal, and technical supplies. In addition there would be the usual housekeeping divisions: budget and finance, legal, personnel, language and conference services, internal audit, and general services. The first year's budget is suggested as $4.089-million, with a $2-million working capital fund.

The Preparatory Commission also named the first 13 of the 23 members of the Agency's Board of Governor's. Chosen were: Australia, Brazil, Canada, Czechoslovakia, France, India, Japan, Portugal, Sweden, Union of South Africa, USSR, U. K. and U. S. The General Conference in Vienna will elect the other ten. Twenty-seven of the 81 signatories of IAEA's statute have ratified it thus far, and more are expected to do so by Oct. 1.



'Ship'—USS A1W—rises in desert

An exact replica of a hull section of a Navy supercarrier is going inside this structure being built at AEC's reactor testing station in Idaho by Westinghouse. Alongside land-based prototype for Nautilus, this facility—A1W—will contain two large pressurized water reactors of advanced design hooked up in tandem to drive one propeller shaft, and associated propulsion machinery. Westinghouse is designing nuclear part of unit; Arthur G. McKee & Co., Cleveland, drew building plans; Arrington Construction Co., Idaho Falls, is general contractor; Eastern Idaho Construction Co. (a subsidiary of Newport News Shipbuilding & Dry Dock Co. which will build first eight-reactor carrier) will install reactors in hull section; Knapp Mills will supply shielding

Newport News Shipyard to Build First A-Carrier; Subs Assigned

The Navy's first nuclear-powered aircraft carrier was ordered last month. Newport News Shipbuilding and Drydock Co. is to build the 85,000-ton, eight-reactor attack carrier, "subject to acceptable contract negotiations." The Newport News, Va., yard, builder of the superliner *United States* and the carrier *Forrestal*, has been studying nuclear propulsion since October 1953, longer than any other U. S. shipyard. It will earn about $150–200-million of the huge ship's estimated $314-million total cost; the rest will be absorbed by the propulsion system, for which Westinghouse is prime contractor. The carrier, as yet unnamed, will take four years to build.

Other construction assignments included one guided-missile A-sub each to the Portsmouth, N. H., and Mare Island, Calif., navy yards (a third remains to be assigned later); and the first small hunter-killer A-sub, for which Combustion Engineering Co. is developing a small reactor, to Electric Boat division of General Dynamics. NUCLEONICS also learned that the seventh *Skipjack*-class sub, last unassigned ship in the 1957 building program, will be built at Portsmouth navy yard.

Swiss Industry Picking Up Momentum on Power Plans; Two New Syndicates Formed to Build Big Reactors

GENEVA

After a rather slow start, Switzerland's nuclear program seems at long last to be gaining speed. 1957 has witnessed so far a series of significant events in this field.

• On May 17th, the country's first enriched uranium research reactor started its active career.

• About the same time, construction of a second—a natural uranium, heavy water—reactor, also for research, was started, to be completed in 1959.

• In July two new corporations were set up which will construct power producing reactors in two different parts of Switzerland—one near Lausanne, to be completed in 1963; the other near Zürich, date of completion still undetermined.

• Finally, the Federal government made public late in July the text of a bill on peaceful uses of atomic energy and protection of the public against radiation.

Reactors, Present and Future

The first Swiss working reactor, inaugurated in May, is the swimming pool purchased from the U. S. Atomic Energy Commission (which had exhibited it on U. N. grounds at Geneva during the 1955 "Peaceful Uses of Atomic Energy" conference). The reactor was entirely dismantled for study purposes, enlarged and modified in several respects, renamed "The Sapphire," and rebuilt in Switzerland's first atomic center at Würenlingen, 20 mi NW of Zürich. Using enriched uranium-235 obtained from the U. S., it is one of Western Europe's most powerful source of neutrons with a full-power output estimated at 10^{13} n/cm²/sec.

Its pool contains 260 yd³ demineralized water, and the reactor itself is suspended at 21-feet depth in the pool, hanging from a rolling aluminum armature attached overhead and remotely controlled. Six irradiation ducts have been added for research purposes.

Four other reactors are at present under study, in varying stages of advancement:

1. The second, 12.5-Mw heavy water research reactor is already under construction at Würenlingen, scheduled for completion in 1959 (NU, June '56, 19B). It is to be built entirely in Switzerland by such firms as Brown, Boveri & Co., Sulzer Brothers, Escher Wyss, Oerlikon Works, and others. Its construction is financed in part by 141 Swiss firms and technical institutes that have set up Reaktor A.G., the largest Swiss corporation for nuclear research, and in part by the Federal government of Switzerland, which has already given the venture subsidies to the amount of 15-million Swiss francs ($3.75-million). The corporation hopes to obtain another 50 million Sw frs shortly from the government and from other interested groups in order to broaden its activities in the nuclear reactor field.

2. The Swiss Federal Polytechnical Institute in Zürich, one of Europe's great technical universities, will build in Zürich itself an underground space-heat reactor of 20 Mw that will produce steam to heat a number of municipal and federal buildings in winter, will generate electrical power in summer, but will serve mainly for research and training purposes.

Three caves will be dug out under the town's main hill—one to house the reactor itself, the other two for safety reasons: in case of an improbable explosion, they would act as safety valves to receive the debris. Moreover, in case of an accident, the entire installation would be completely flooded with water.

This reactor will be built by the Polytechnic with the aid of a federal subsidy.

3. A small power reactor, the first in Switzerland, is to be built in Lausanne in time to furnish electricity for the 1964 Swiss National Exhibition in that town. A group of fourteen industrial corporations in French-speaking Switzerland set up a new joint corporation in July for the development of power reactors in that part of the country. Called Energie Nucléaire S.A., this new corporation (whose general manager is Daniel Bonnard, associate director of the Lausanne Hydraulics Laboratory) intends first to build a small pilot power reactor to be completed by the end of 1963.

Complete details are not yet available, but it has been learned that the National Exhibition Reactor will be a boiling water type of 20 Mw and 5 Mw, using a heat exchanger. Moderately enriched uranium in oxide form will be used as fuel. It will be constructed underground in the outskirts of Lausanne. Cost is expected to be 25–30-million Sw frs ($6–8-million).

The corporation's capital is set at 5-million Sw frs, of which 600,000 frs have so far been paid in by various industrial concerns, public utility companies, and the municipality of Lausanne. It is expected that other large towns of French Switzerland, as well as the Federal government, will participate financially in the venture.

4. On June 19, four of the largest electricity producing corporations of Switzerland: Aare-Tessin A.G., Bernische Kraftwerke A.G., Nordostschweizerische Kraftwerke A.G., and S.A. l'Energie de l'Ouest Suisse, decided to set up a joint 6-million Sw frs ($1.5-million) corporation, called Swissatom S.A., with the intention of building a small pilot 10–15 eMw power reactor intended mainly as an experiment and in order to test the economic feasibility of further power plants. Having neither coal nor oil resources, Switzerland is already highly electrified. When the last dams now under construction in the high Alps are completed in a year or two, the country will have no further hydroelectric potential to tap.

The type of reactor to be built has not yet been decided. Swissatom S.A. thinks it will probably have a power of 50 Mw and will be built either in the southern part of the country in the Italian-speaking canton of Ticino, or near Zürich, Switzerland's main industrial town. It is to serve as a forerunner for larger production reactors to be built later.

Finally, the establishment of two more corporations specializing in the manufacture of components and the construction of reactors is being

studied by interested groups: Atomkraft A.G., and Atomelectro S.A.

Over-all Program

All in all, it has been reliably estimated that Switzerland will spend over 100-million Sw frs ($25-million) for nuclear reactors and related projects during the next five years—excluding Swiss contributions to OEEC work in this field.

Enriched uranium has been obtained from the U. S. under a bilateral agreement. Negotiations are at present going on with Britain and Canada for purchase of natural uranium and for admission of Swiss students to nuclear research institutes in those countries. A similar agreement with France was signed in July, providing for delivery of uranium by France and of nuclear equipment by Switzerland, as well as exchange of information and of specialists and the like. Contacts have also been initiated with Italy, and a group of Swiss nuclear physicists visited the Italian atomic center at Ispra in July.

New Legislation

A bill on peaceful uses of atomic energy and on protection against radiation was prepared by the Federal government and published in July by Otto Zipfel, government delegate for atomic energy problems.

Highlights of the draft law are:

The Federal government could subsidize research in nucleonics and the training of nuclear physicists. It alone would have the right to purchase nuclear fuels and grant their use to authorized atomic plants, universities and research institutions under certain conditions. Construction and exploitation of nuclear plants is to be subjected to special authorizations. Only the Federal government will grant such authorizations. Thus cantonal (state) governments will have no more say; until now they alone had control over industrial plants.

The bill regulates in detail the production, processing, uses, storage, transportation, sale, purchase and possession in any form of nuclear fuels, residues, and other radioactive materials, as well as the transit and export of fissionable material.

A chapter on insurance sets a maximum of 150,000 Sw frs ($37,500) per person in case of death or injury, and requires each atomic plant to contract a minimum total liability insurance of 20-million Sw frs. This also applies to any firm that handles or possesses nuclear fuel or residues. The bill also provides that the Federal government may grant help in cases where damage incurred may surpass the insured amounts.

The government plans to build 24 control stations for constant measurement of radioactivity in the atmosphere.

Manpower Problem

One of the most difficult problems is the present dearth of specialists in the nuclear field. Although each year Switzerland exports hundreds of engineers, it has not yet trained a sizable number of nuclear physicists. It has a few outstanding teachers in this field, but too few students are as yet attracted by nuclear studies. It has been estimated that Switzerland needs at least 400 nucleonics specialists; it has less than one-tenth of this number. And those who now graduate in this field nearly always emigrate to other countries as soon as they complete their studies: they get much better-paid jobs abroad than in Switzerland.

To train more physicists and retain as many as possible in the country, several Swiss universities have now decided to create larger and better-equipped nuclear physics institutes. Berne, for instance, will spend 10-million Sw frs ($2.5-million) for its institute, Lausanne 4.5-million Sw frs, etc. Moreover, special subsidies will be granted to these institutes by local and/or the Federal government in order to improve the pay of their technical and scientific staff.

A Who's Who of Italian Reactor Builders: Seven Groups Active in Nuclear Power Field

Two announcements in the U. S. last month of aid to Italian power reactor projects focused attention on a welter of such projects now being promoted in that country.

The two announcements concerned:

- The International Bank for Reconstruction and Development (World Bank) has concluded an agreement with the Italian government for joint sponsorship of a study to lead to construction of a 150-Mw station in underdeveloped southern Italy. Called Project ENSI (Energia Nuclear Sud Italia), the study will include selection of a site, preparation of invitations to manufacturers, on an international basis, to bid on construction of the plant, and review and evaluation of the bids. The plant will probably be built between Rome and Naples.

  Overall direction of the project is in the hands of a two-man steering committee: Felice Ippolito, secretary general of CNRN (Comitato Nazionale per le Richerche Nucleari, the official Italian nuclear research and development body), and Corbin Allardice, atomic energy adviser to the World Bank. The U. K. Atomic Energy Authority and the U. S. AEC have agreed to act as nuclear engineering consultants, with the former arranging for technical review of gas-cooled natural uranium reactor proposals, the latter of enriched systems. An international panel of specialists is to be set up by the Bank to review the bids and the AEA and AEC reports; it will be chaired by a Canadian and have two members each from the U. S. and U. K. and one each from France and Italy.

  This panel's reports will in turn go to the Italian nuclear power syndicate SENN, which will make the final selection of the best bid. SENN recently selected Internuclear Co. of Clayton, Mo., as consulting engineers for design and construction of the plant (NU, June '57, 27; Aug., 118). NUCLEONICS' Rome correspondent advises that the Italian government has asked the World Bank for a $50-million loan for this project, and that the Bank is reportedly considering it favorably.

- A program for two power reactors —one U. S., one British—has been launched by the state fuel monopoly ENI. One ENI subsidiary, AGIP Nucleare (*see below*), will build a Calder-type power station, and has already concluded a technical assistance agreement with the U. K. Atomic Energy Authority—first of its kind entered into by AEA. Under it, AEA will supervise the program's preliminary studies and advise during the construction and early operation stages. Negotiations already underway with four British manufacturing consortiums are expected to be concluded by year's end.

  Another Italian syndicate, SIMEA,

has contracted with Vitro Engineering Co. of New York for consultation services during design, construction and the first six months of operation of a 500 Mw, 133 eMw pressurized water reactor station to be built near Rome. This $46.4-million plant is to be ready by early 1962. Babcock & Wilcox received SIMEA's letter of intent in May on furnishing the reactor proper, but it is intended that as much of the components, equipment and construction work as possible be done by Italian firms and that only those items be imported that Italian industry cannot yet supply. The reactor will use enriched uranium; unlike B&W's Indian Point plant for Con Edison, it will not have a thorium blanket.

Scorecard for Telling Players

With this increase in activity in the Italian nuclear world, the alphabet-soup of Italian organizations is becoming almost as difficult to thread one's way about in as that of U. S. reactors. NUCLEONICS presents herewith a guide to Italian nuclear organizations.

ENI (Ente Nazionale Idrocarburi = National Hydrocarbon Trust) is the Italian state-controlled gas and oil monopoly; it assumed governmental responsibility for national energy sources. In October 1955 it set up

SOMIREN (Società Minerali Radioattivi Energia Nucleari) to prospect, mine and process minerals containing fissionable material. The following year ENI set up

AGIP Nucleare, a holding company to promote new nuclear activities through subsidiary companies, including mineral prospecting, mining and processing; fuel element fabrication; power generation, and chemical reprocessing; also cooperation with other Italian and foreign groups in the field.

IRI (Istituto per la Ricostruzione Industriale = Institute for Industrial Reconstruction) is a government-controlled, bank-like holding company with subsidiaries in banking, shipping and transport, ferrous metals, chemicals, mining, agriculture, telephone, radio and television —and electric power. In October 1956 IRI and ENI announced a decision to collaborate to build a 100-eMw nuclear plant for southern Italy (NU, Dec. '56, R11), and for this purpose they created

SIMEA (Società Italiana Meriodionale Energia Atomica = Southern Italian Atomic Energy Company). Shares in SIMEA are controlled 75% by ENI through AGIP Nucleare, while the 25% held by IRI is divided among Finelettrica—the IRI power company—and other subsidiaries.

SORIN (Società Ricerche Impianti Nucleari = Nuclear Power-plant Research Co.) was set up jointly a year ago (NU, Sept. '56, R6) by Fiat and Montecatini to develop nuclear equipment and build nuclear power stations. It has recently contracted with AMF Atomics for a 1-Mw swimming pool for industrial research, isotope production and personnel training (NU, July '57, 25). The group is also said to be considering a 134-Mw Westinghouse or B&W pressurized water reactor. Fiat recently signed an agreement with Westinghouse to manufacture reactors under license for sale in Italy (NU, Aug. '57, 19).

SELNI (Società Elettronucleare Italiana) is a syndicate set up by the leading power companies to build nuclear stations. 85% of its shares are privately-owned, 55% by Edisonvolta of Milan; the other 15% are held by IRI. It is responsible for the project to install a 134-Mw Yankee-type pressurized water reactor in Edisonvolta's grid, for which the latter has given Westinghouse a latter of intent (NU, Jan. '57, R1). A conventionally-powered superheater would bring total electric capacity to 225 Mw.

SENN (Società Elettronucleare Nazionale), another syndicate, is planning the big nuclear station for southern Italy which the World Bank will help finance (*see above*). SENN includes all southern utilities plus one in Sicily, is 85% state-, 15% privately-owned. It is clearly the government's "chosen instrument" in the nuclear power field.

(At the time the Italian power bilateral was being negotiated in Washington (see p. 25), the Italian negotiators sought fuel for four large power stations, one each to be built by SELNI, SENN, SORIN, and SIMEA. AEC okayed the first two, on the ground that Italy was not yet prepared to handle more than two such projects at this time.)

National Bodies

CNRN (Comitato Nazionale per Ricerche Nucleari = National Committee for Nuclear Research) is the government body set up in 1952 and entrusted with translating government atomic policy into fact. Its scope is seen in its ten study groups that range from fundamental research, geo-minerology, reactor projects, and reactor materials, through isotopes, economics, legislation, and personnel training, to protection and location of plants, and civil defense. On the fundamental research side, CNRN operates through

INFN (Istituto Nazionale di Fisica Nucleare = National Institute of Nuclear Physics), which is associated with the physics institutes of nearly all the universities of Italy. INFN is building, with CNRN financing, a

Frascati National Laboratory 12 mi S of Rome, where a 1-Bev electron synchrotron, hot and cold labs are well along in construction.

Applied Research

On the applied research side, CNRN is helping to finance the

Ispra Nuclear Center on the shore of Lake Maggiore, near Varese. Here is being built a CP-5-type heavy-water research reactor by ACF Industries; Vitro was design consultant on the reactor building.

The reactor is scheduled to start operating next spring. It is a project of, and will be operated for CNRN by,

CISE (Centro Informazioni, Studi ed Esperienze = Center for [Nuclear] Information, Studies and Experiments), set up in 1946 by private interests and for some five years the only organization doing work in applied nucleonics. It was reorganized in 1956 as half privately-, half State-owned. CISE is also doing work in experimental and solid state physics, reactor control systems, chemistry and physical chemistry, metallurgy and gaseous diffusion.

Training

The Politecnico—the engineering faculty—at the University of Milan has set up the

Centro di Studi Nucleari Enrico Fermi, which has just ordered a 50-tkw solution-type research reactor from Atomics International (NU, Aug. '57, 26).

Besides this, SORIN, and Ispra, there are three other research reactor projects planned or contemplated at present:

- For the center at Frascati, a 1-Mw swimming pool;
- For the University of Pisa, a 3–5-Mw swimming pool;
- For the University of Cagliari (Sardinia), a subcritical reactor.

ROUNDUP

Reactor News

BIDS ASKED ON GAS-COOLED SHIP UNIT

A new forward step in development of economic nuclear propulsion for merchant ships was taken when AEC and the Maritime Administration issued an invitation to industry to submit proposals to develop a closed-cycle gas-cooled reactor-and-turbine system. To the best proposal will go a contract for development and design of a land-based prototype of this advanced reactor plant. The AEC–MA group hopes that the prototype may be completed 5–7 years from award of the development contract. Of the six study contracts awarded last year (NU, July '56, R10) by MA for examination of advanced nuclear propulsion systems, three involved gas-cycle types: Ford Instrument Co. studied nitrogen-cooled, graphite-moderated reactors; General Motors' Cleveland Diesel engine division (together with Foster Wheeler Corp., Internuclear Co. and Bailey Meter Co.) studied helium-cooled, graphite-moderated systems, and General Atomic division of General Dynamics looked at hydride-moderated units. Said the joint AEC-MA group: "It has been concluded from these studies that further work should be undertaken to verify the high promise of this [gas-cooled] system." (In addition, Atomics International worked on organic-moderated and -cooled reactors, AMF Atomics on closed-cycle boiling water units, and Babcock & Wilcox on advanced pressurized water reactors.) Preliminary reports on these six studies were presented at the merchant ship symposium in Washington July 30 (NU, Aug. '57, 19). This development program is parallel with another being conducted by MA alone, for design and construction of a 12,000 shp closed-cycle gas turbine engine to power a Liberty ship, to be tested with an oil-fired source but suitable for subsequent use with a reactor. MA is now considering five bids (NU, Dec. '56, R1; March '57, R5).

FIRST THIRD-ROUND BID APPROVED

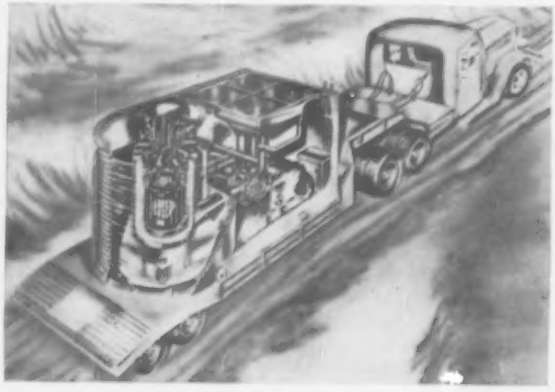
Northern States Power Co.'s proposal for a 66-Mw (electric) recirculating boiling water power reactor (NU, March '57, R9; June, 18) was accepted by AEC as a basis for contract negotiations, first under the third round of the Power Demonstration Reactor Program. (One other proposal under the third round, by the Florida Power Group for a 136-Mw natural-uranium heavy-water unit, is under consideration.) AEC says "a major contribution to the advancement of nuclear reactor art" will be made by the recirculating boiling reactor to be built by Allis-Chalmers for Northern States and ten other electric utilities associated with it in Central Utilities Atomic Power Associates. The plant, to cost $21-million, is to be completed by June 30, 1962.

YANKEE CONSTRUCTION PERMIT HELD UP

AEC's fifth construction permit for a power reactor went early this month to Yankee Atomic Electric Co. for its Westinghouse-designed pressurized water plant at Rowe, Mass. But instead, AEC—which on Aug. 2 had given 30-day notice of intention to award the permit—is scheduling hearings early in October in the case, as required by the new indemnity law which calls for compulsory hearings on all applications for building power reactors. AEC says Yankee may still get its permit later in October. Earlier permits had gone to Consolidated Edison's Indian Point plant near New York, Commonwealth Edison's Dresden Station near Chicago, Power Reactor development Co.'s Fermi fast breeder near Detroit (a permit challenged by three labor unions and now the subject of long-drawn-out administrative hearings), and General Electric's pilot boiling reactor at Vallecitos, Calif. (*see p. 21*). AEC's announcement on Yankee disclosed that the previously accepted electric power rating of 134 Mw would be reached only on the second core and that the first core would produce but 110 Mw. Completion date is given as between December 1959 and June 1961.

ARMY WORKING ON MOBILE A-POWER

Army Engineers and AEC have this truck-mounted mobile reactor power plant "under active development," but it is admittedly a very long-range project, far from the construction stage. The plant as contemplated



would have a capacity of "several hundred kw"; it would comprise a gas-cooled reactor coupled to a closed-cycle gas turbine, mounted on a standard 25-ton trailer. The plant could be airlifted complete in one C-124 Globemaster. Use of gas cooling makes plant as free from water-supply as from fuel-supply problems.

PRIVATE TEST CENTER SOUGHT

A new syndicate to build and operate a privately-financed nuclear test center is being proposed by ACF Industries, Kaiser Engineers, Lockheed Aircraft Corp. and Phillips Petroleum. The center would include a very-high-flux test reactor for component irradiation and production of high-specific-activity isotopes, and supporting laboratories. A study group of scientists and economists has been set up under R. M. Jones of ACF to examine feasibility.

TRAMP OPERATOR STUDYING A-PROPULSION

American Foreign Steamship Co., U. S. operator of bulk cargo carriers in world-wide tramp trade, has retained American Nuclear Science Corp. of New York as consultant on the technical and economic aspects of nuclear propulsion for ships. The ship operator, which is now building its first tanker, "wants to be prepared to listen and if advisable to act."

DUTCH REACTOR HAS GROWING PAINS

The 10-kw AMF Atomics swimming pool on exhibit at the Dutch atomic energy show in Amsterdam was shut down for 3 weeks to remove an ionization chamber, monitoring reactor radiation level, that had short circuited; and one fuel element whose cladding showed corrosion. Both components were replaced and the reactor put back in operation.

World News

U. K. Picks Welsh Sites, OK's Hunterston

Wales finally has its nuclear power plant site—perhaps two. Trawsfynydd in Merionethshire has been chosen by the U. K. Central Electricity Authority as site for its fourth, Britain's fifth (Hunterston, in Scotland, does not come under CEA) power-first nuclear station (NU, April '57, 21). Following Bradwell, Berkeley, and Hinkley Point, Trawsfynydd is to be in service by 1962. The site offers a good rock foundation, and lies on the shore of a storage reservoir with a cooling water supply adequate for a 500-Mw station. Also mentioned as a suitable site for a later and even larger plant—because of its unlimited water supply—is Edern in Caernarvonshire. . . . Meanwhile after long public hearings, the site at Hunterston, Ayrshire, was approved for the South of Scotland Electricity Board first A-plant. The 320-Mw, $104-million two-reactor station to be built by General Electric Co. and Simon Carves may be the world's largest when completed (NU, Dec. '56, R2; Jan. '57, R5).

British Briefs

The Atomic Energy Authority will study the properties of thorium as fuel for high-temperature gas-cooled reactors, has given the General Electric Co. a contract for design and construction of a critical assembly to test the feasibility of operating at temperatures up to 1,400° F using Th in ceramic—probably carbide—form. Breeding of U^{233} may be possible. The facility is to be built at the new reactor research station at Winfrith Heath (NU, March '57, R10). . . . Britain exported more than half—56%—of the $1.5-million worth of radioisotopes she sold last year. Total production was 12% above the previous year. . . . The sixteenth and last heat exchanger at Calder Hall was hoisted into position last month alongside the fourth reactor. . . . Britain will supply Norway with 9 tons initial charge of uranium fuel elements for the latter's process steam reactor at Halden (NU, July '57, 56). (The U. S. has shipped 16 tons of heavy water to moderate the reactor.)

Japanese Jottings

The Japanese Atomic Energy Research Institute plans to import a small power reactor to generate 15 Mw in the very near future. JAERI wants a pressurized or boiling water reactor for experimental purposes; its project has no connection with the long-maturing plans of the government and the utilities to import a large British or U. S. power reactor. . . . Japan's first reactor, the Atomics International-built 50-kw solution-type research unit, went critical last month at JAERI's Tokai site 70 mi NW of Tokyo. . . . The Transportation Ministry plans to spend 4.3-billion yen ($11-million) starting next year on a three-year research program on construction of nuclear-powered ships. . . . Kawasaki Heavy Industries, a leading shipyard, will build a 40,000-ton, 20,000-shp nuclear tanker for entry into service by 1965.

Forward Strides in Germany

West Germany's first five reactors—all research units—will soon be in operation, the Atomic Ministry says. The Atomics International solution-type reactor in Frankfurt and the AMF Atomics pool-type at Garching near Munich are to start up by end of this month, and another AI solution unit for West Berlin is to be delivered disassembled this month and be completed and functioning by year's end. A Babcock & Wilcox pool in Hamburg and a British Merlin-type pool for the Düren research center are to start up next year (NU, Oct. '56, R10; June '57, 27) . . . Farbwerke Höchst will start heavy water production on this fall, using liquid-hydrogen distillation at a temperature of −250° C. The $1.7-million facility will turn out 6 tons/yr, 800 gm/hr. Price will be about the world market price of 24¢/gm as compared with the U. S. price of 6¢/gm, but Höchst expects to find a ready domestic market as it will sell with no strings attached: U. S. supplies of D_2O are available only on condition U. S. engineers are admitted to the buyer's plant, the Germans say. Two German heavy-water-moderated reactors now planned will need between them 32 tons starting inventory plus 1.6 tons/yr replacement. . . . Two firms have started production of reactor-grade graphite. They are Graphitwerk Kropfmühl of Munich, and Siemens-Plania Chemische Fabrik Griesheim of Meitingen near Augsburg, a subsidiary of Höchst and Siemens.

U-Separation in Congo?

A multistage hydroelectric project in the Belgian Congo of stupendous size may come into the Euratom picture as a source of cheap pumping power for a gaseous diffusion plant. Belgium's Inga project involves an initial installation in the Van Deuren valley of 1,000–1,600 Mw capacity capable of expansion to 2,400 Mw without damming the Congo; thereafter a major dam could realize a potential as high as 40,000 Mw (*not* kw). Word to NUCLEONICS from Brussels is that the "three wise men"of Euratom were "amazed" on learning the details of this project, after filing their report (NU, May '57, 20; June, 25), and that they said they would not have recommended against a diffusion plant for Euratom on the ground of high operating cost had they known of it.

Research Reactor for Georgia (USSR)

Construction of a research reactor has started in Georgia, according to Radio Tiflis. The new Transcaucasian Nuclear Center will serve the Georgian, Armenian and Azerbaijan SSRs.

Hinton Leaves AEA for New Power Post

Sir Christopher Hinton left the U. K. Atomic Energy Authority Sept. 1 to assume broader tasks as chairman of the newly-established Central Electricity Generating Board, set up to replace the Central Electricity Authority, which will cease operations Dec. 31. The new CEGB will direct and control both thermal and nuclear power in Britain. Sir Christopher, director of AEA's Industrial Group since its formation in 1946, is credited more than any other single man with the building of Calder Hall.

Burma Formulates Nuclear Program

The Union of Burma Atomic Energy Center has formulated a two-step atomic energy program, based on the recommendations of a U. S. consultant—Richard F. Humphreys, assistant director of the Armour Research Institute. The program includes a nuclear laboratory equipped to handle radioisotopes, and a reactor to produce isotopes. Such facilities would call for a staff of 20 to 30 researchers and a curriculum to train about 20 technicians annually.

News in Brief

Plowden, Strauss to Speak in Nuclear Week

The heads of the U. S. and British atomic energy programs will share a New York platform Oct. 29 to provide a main feature of Nuclear Week, one of the most formidable concentrations of atomic conferences yet scheduled. The Lewis L. Strauss–Sir Edwin Plowden talks will be at the all-conference banquet at the Waldorf-Astoria. Besides the fourth annual meeting of the Atomic Industrial Forum, the second winter meeting of the American Nuclear Society, and the third annual Trade Fair of the Atomic Industry, there will be a two-day meeting of IRE's professional group on nuclear science, and a special reactor safety session jointly sponsored by AEC, ANS and the Forum.

"1957 Nuclear Industry—Problems and Progress" is the theme of the Forum meeting, which will include 20 sessions in three days. Topics are:

Monday morning, Oct. 28—Research and test reactor progress; uranium production; radiation application; appraisal of the atomic industry.

Monday afternoon—U. S. power reactor experience; reactor fuel reprocessing; radiation instrumentation; financing.

Tuesday morning—U. S. reactor program in review; reactor fuel manufacture and handling; progress in nuclear standardization; legal problems.

Tuesday afternoon—Atomic activities outside U. S.-I; reactor components and accessories manufacture; economic incentives; information and training.

Wednesday morning—Factors affecting power reactor construction; atomic activities outside U. S.-II; marketing; nuclear insurance and protection.

The ANS meeting will be highlighted by a special nine-paper session on the Army Package Power Reactor, and two special sessions on reactor control materials. Other sessions will include four on reactor theory, and two each on reactor engineering, reactor kinetics, reactor concepts and evaluations, experimental reactor physics, and critical and exponential experiments. Single sessions will cover chemical and fuel processing, metallurgy and fuel elements, radiation effects on graphite, reactor safety, experimental techniques, and heat transfer and shielding.

Metals & Controls Expands

The nuclear products division of Metals & Controls Corp., Attleboro, Mass., a pioneer maker of solid fuel elements, is to be made a wholly-owned subsidiary company on Jan. 1, under a name and officers not yet set.

A Beryllium Plant—and Another

A former locomotive roundhouse renovated for $4.5-million was dedicated last month as the new Nuclear Division of the Beryllium Corp. where reactor-grade beryllium is to be produced. At the ceremonies, Beryllium Corp. president Walter R. Lowry announced a second plant will be established in the former railroad shops, adjoining the onetime roundhouse of the Lehigh Valley R.R. at Ashmore, east of Hazleton, Pa. Beryllium Corp. was one of two firms—Brush Beryllium being the other—to get AEC contracts last year (NU, Sept. '56, R2) for a total of a million lb of Be over five years: 100,000 lb per company per year. Beryl ore containing about 11% beryllium oxide will be the raw material at Ashmore, the BeO being extracted by the fluoride process and then reduced to metal in the form of 9-in. dia billets weighing some 75 lb. AEC's contract price is about $47/lb as compared with $85/lb formerly; the new plant will permit economies previously unattainable in Be production. The second plant, which will cost an additional $1.25-million to renovate, will be a fabricating facility, to complement the raw material processing first plant.

Fusion Info Access Broadened

AEC has amended its access permit regulations to liberalize the conditions for access to secret data on controlled fusion. Access is now possible also to those "making a substantial financial contribution" or furnishing scientific, engineering or other services "directly related to a comparative evaluation" of fission and fusion power, or for a study or research and development program in the thermonuclear field. Previously (NU, June '56, 20B; Aug. '56, R8), fusion information was available only to those who are either "directly engaged in a substantial effort" to develop or build a fission reactor, or to those demonstrating capability of making a significant contribution to controlled thermonuclear research and development.

World Nuclear Standards Planned

The U. S., U. K., USSR, and 10 other nations agreed to establish world standards in the civilian atomic energy field, and took the first steps to that end at a meeting of the International Organization for Standardization in Geneva (NU, Aug. '57, 28). Technical Committee 85 (on nuclear energy) will meet again in June at Harrogate, England, to study a trilingual glossary, radiation protection, and reactor safeguards.

Management Course Goes to Greece

Athens will be the scene, in May 1958, of the third atomic energy course for management being sponsored abroad by ten U. S. nuclear-oriented firms. This is due to the interest of Queen Frederika of Greece, an enthusiastic student of nuclear development, who attended the first course in Paris in January (NU, Nov. '56, R8). The second course is being given this month at the Belgian resort of Knokke. Future plans include a fourth course in Germany in the fall of 1958, later editions in Japan and South America, and an all-European industrial atomic energy congress in Brussels in May, 1959, with a concurrent trade fair. The course is a management seminar to acquaint industrialists, business executives and government officials with nuclear fundamentals, applications and potentials. About 200 may attend each course, tuition fee for which is $325.

Loftus Adds Nuclear Department

A nuclear engineering section has been established by Peter F. Loftus Corp., Pittsburgh consulting engineers, to furnish nuclear design and consulting engineering services to electrical utilities and other industries.

Illinois Licenses Radiation Sites

Illinois became the ninth state to enact legislation requiring radiation facilities to be licensed. Registering began last month and must be completed by Jan. 1958.

Cobalt-60 Prices Reduced

A new price schedule, ranging from $2 to $5 per curie, has been established for Co^{60} by AEC. The revised pricing, based on quantity orders, compares with the previous charges of $2–10 and no provision for bulk order discount. With current annual production at 300,000 curies, AEC has sold about 121,000 curies to licensees during the past year.

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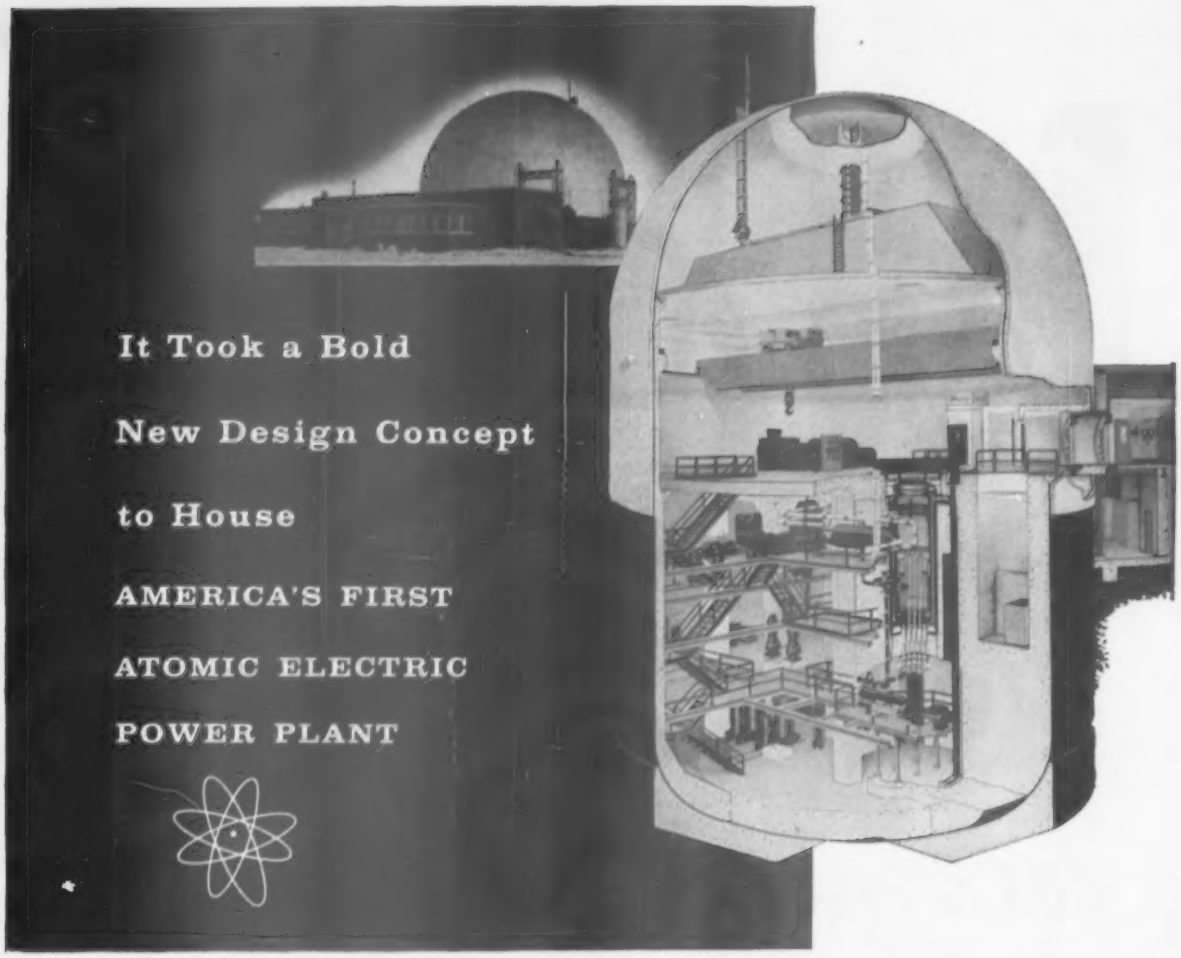

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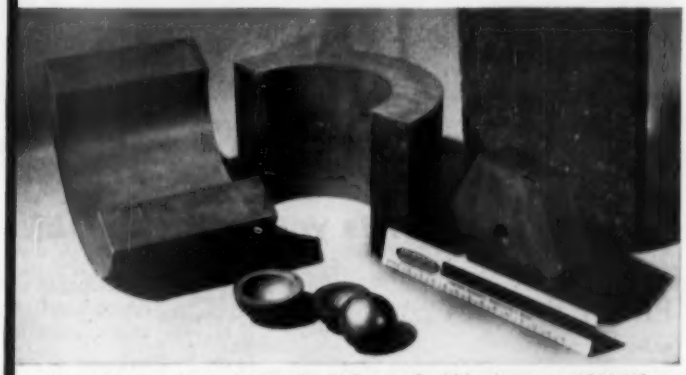

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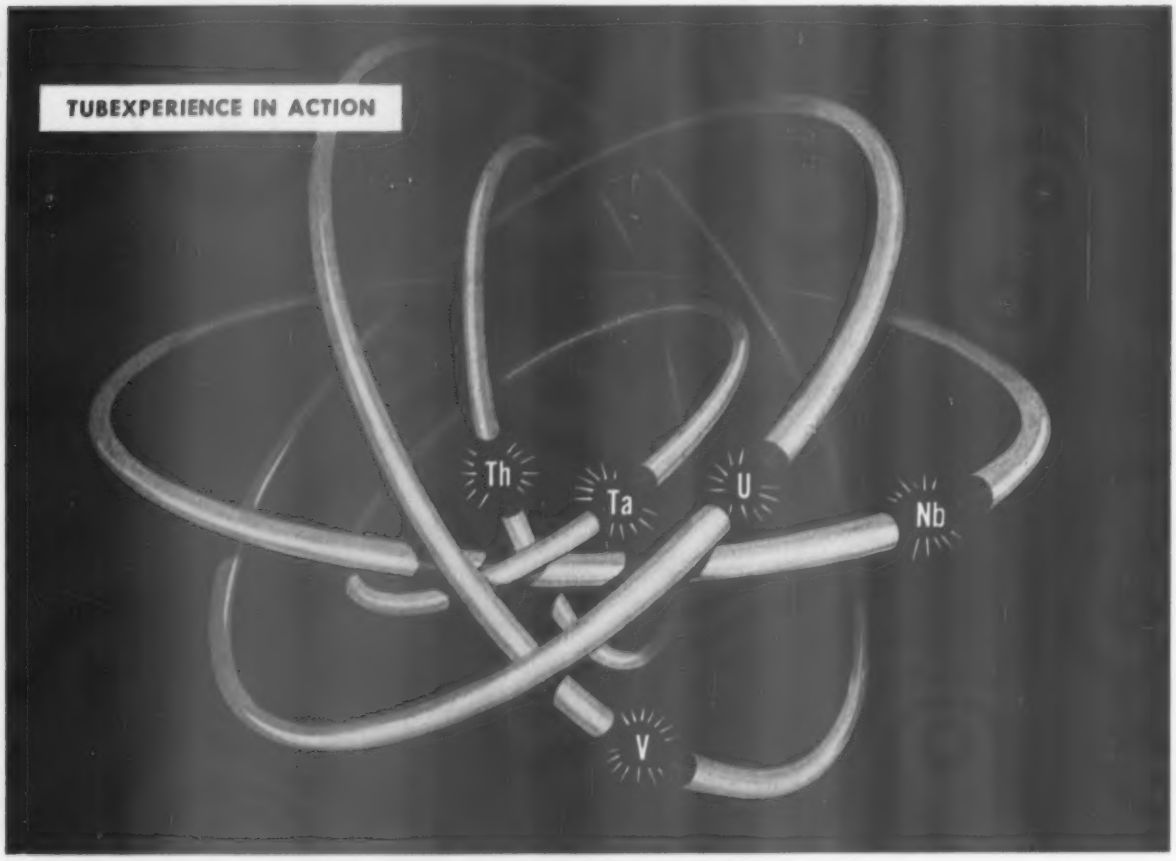

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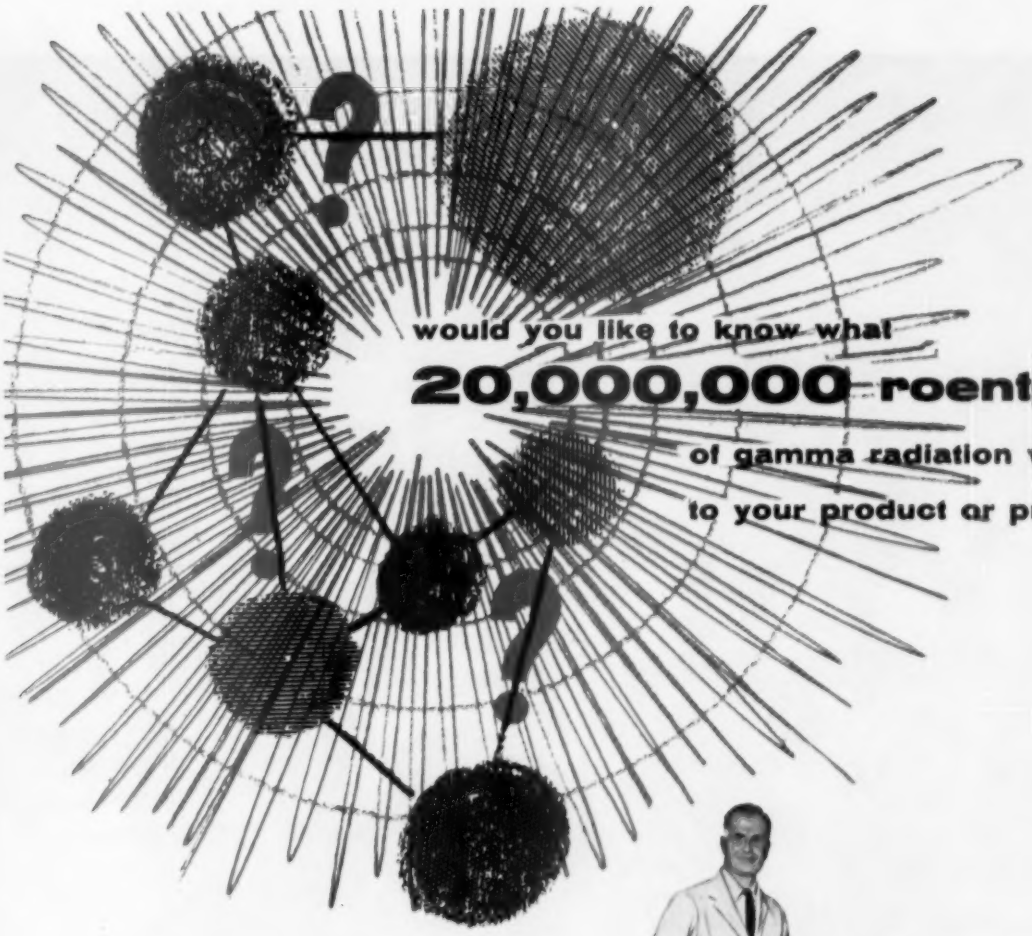

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Photos Courtesy Argonne National Laboratory

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EBWR makes

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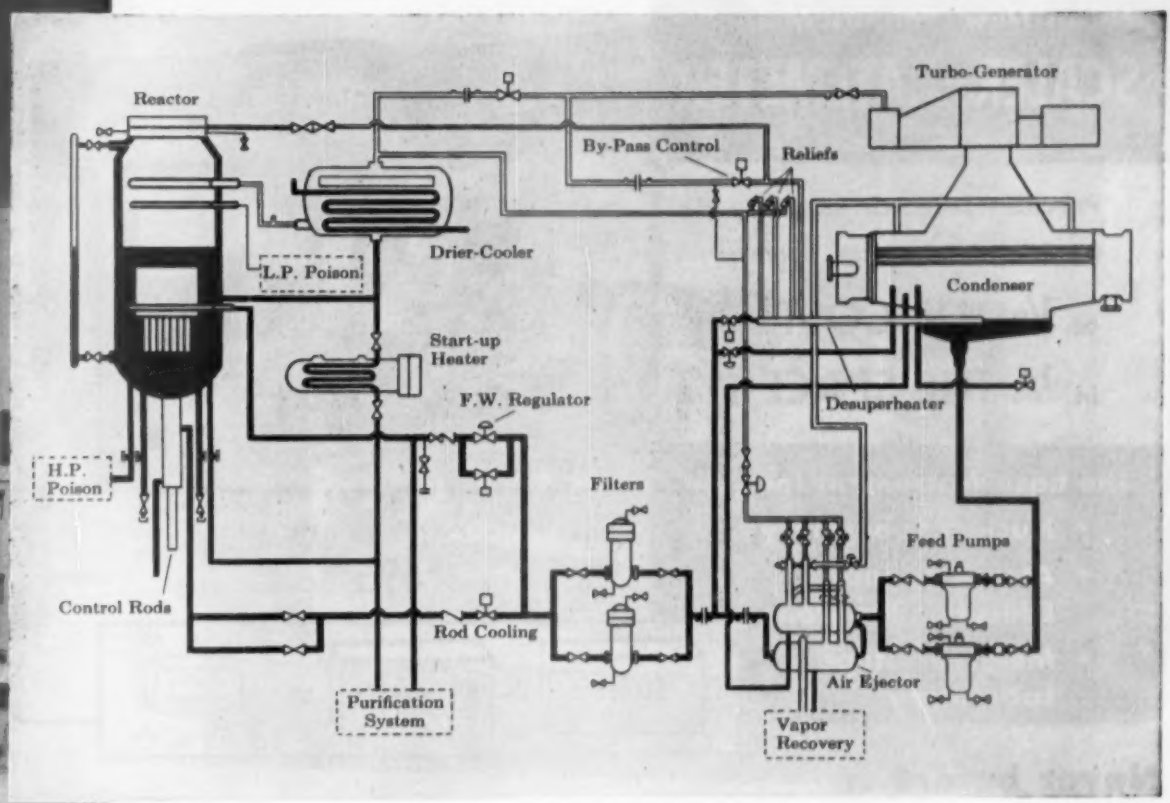

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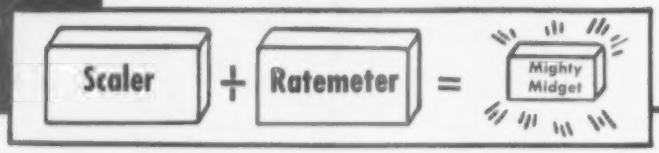
- Medical Isotope Laboratory



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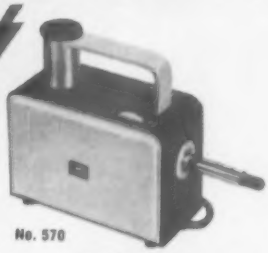

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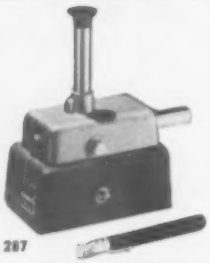

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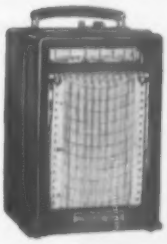

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10,000 kw light water materials testing reactor for the Nuclear Engineering Test Facility, Wright-Patterson Air Force Base, Ohio

A preliminary design of a 10,000–20,000 kw light water materials testing reactor for the Case Institute of Technology

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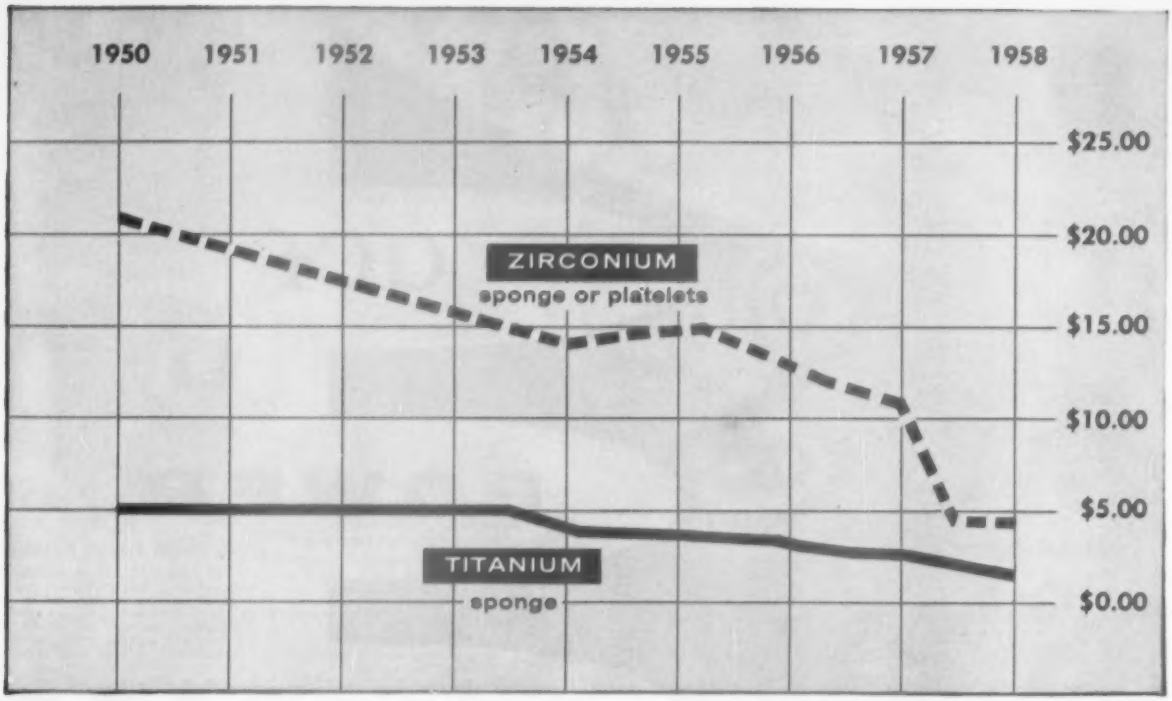

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ZIRCONIUM AND TITANIUM FOR INDUSTRIAL USE

Now is the time to do some new thinking about titanium and zirconium. These metals with their many advantages will soon be *much more plentiful* at *much lower cost.* Reason: U.S.I. will be coming onstream shortly with a 10-million pound per year titanium plant AND a zirconium plant which will supply one million pounds of that metal to industry.

Zirconium from the new plant will sell for considerably less than current prices. Here's why: U.S.I. will use the most economical production technique ever developed for reducing metallic chlorides — a semi-continuous sodium reduction process. This process has possibilities of reducing titanium prices in the future as well.

So think again about zirconium and titanium for industrial equipment. Remember that they are lighter than other metals — a pound goes farther. Remember that they are more durable than other metals—a fabricated product lasts longer.

Write to Bill Greenleaf, U.S.I. Manager of Metals Department, for more information on these new metals from U.S.I.

WHAT CAN YOU DO WITH TITANIUM AND ZIRCONIUM AT LOWER PRICES?

In the future titanium sponge prices are expected to drop to about $2.00 a pound, with a corresponding drop in the prices of mill products. At these prices the exceptional strength-to-weight ratio and corrosion resistance of titanium can be put to work in the aircraft, marine, automotive, chemical and allied fields.

Or consider the eventual price of U.S.I. commercial grade zirconium: an estimated $3.00 a pound for platelets and 2 or 2½ times this price for the average mill product. This price will make zirconium practical for chemical equipment, marine equipment, food equipment and surgical metals among other uses. Zirconium has light weight, high structural strength, excellent corrosion and heat resistance; and reactor-grade zirconium has outstanding nuclear properties.

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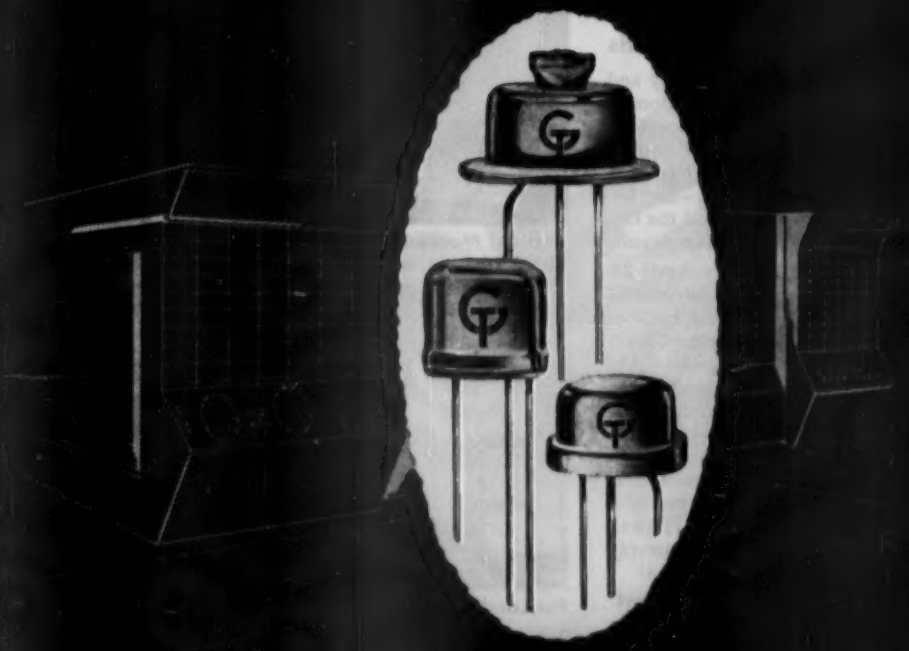

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NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Continuing Progress at AI Advances Nuclear Technology For Many Tasks, in Many Lands

Highlighting progress in the many and diversified reactor programs at Atomics International are significant developments in the two major power reactor approaches underway by AI for the Atomic Energy Commission—the Sodium Reactor Experiment and the Organic Moderated Reactor Experiment.

Forecasts Confirmed. On April 25 the 33rd fuel element was introduced into the SRE, and sustained nuclear fission was achieved. The critical loading confirmed earlier calculations. On July 12 heat from the SRE reactor was used by the Southern California Edison Company to generate electricity. This power was fed over utility lines to Edison consumers. Data obtained from the SRE will be used in the design of a 75,000 kw Sodium Reactor power plant proposed for the Consumers Public Power District of Nebraska.

Power Ashore, Propulsion Afloat. Similar studies are starting on the OMRE, recently constructed at the AEC's National Reactor Testing Station in Idaho Falls. This program will assist in the design of two 12,500 kw power stations, one in Piqua, Ohio, and another in a Latin American country. At the same time, the Organic Moderated Reactor is under study as a most promising nuclear propulsion system for the special needs of supertankers.

Reactors for the World. The Armour Research Reactor, first private industrial nuclear facility, is now being followed by a stream of similar research reactors—for Japan, Denmark, West Germany, West Berlin and Italy—constructed, shipped, and installed by Atomics International. AI's latest development is the compact Laboratory Reactor, available on a short delivery schedule at very low cost to meet the need for nuclear training and research in universities and industrial laboratories.

ATOMICS INTERNATIONAL is a leading designer and builder of reactors for America and for the world. For help on your reactor plans, write: Director of Technical Sales, Department C-74, ATOMICS INTERNATIONAL, P. O. Box 309, Canoga Park, California. Cable Address: ATOMICS.

Critical Moment: On April 25, the SRE achieved sustained nuclear fission. Electricity was generated on July 12.

Destination—Denmark: Nuclear reactor components from AI are hoisted aboard a freighter for Copenhagen.

For Land and Sea: A versatile nuclear reactor concept—the OMRE.

Nuclear Research in Japan: Home of Far East's first reactor will be Japan's Atomic Energy Research Institute.

New Laboratory Reactor: Eight-foot-high tank contains fully functional core, coolant and moderator.

Reactor Hardware for Germany: Components for two German reactors in work at ATOMICS INTERNATIONAL.

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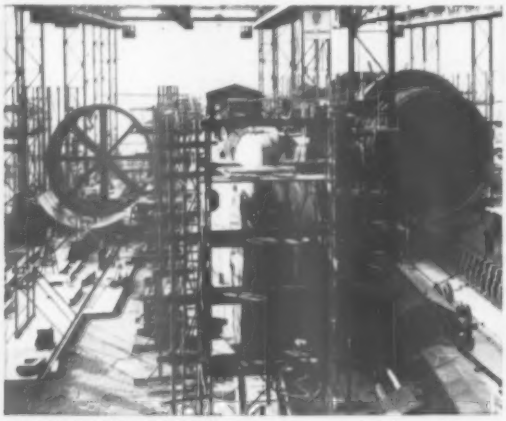

FASTEST AND LARGEST. TUBE-TURN Welding Fittings will be used for coolant piping of the "Skipjack" (on left), and for all main coolant piping of two-reactor sub "Triton" (on right), the largest sub. These nuclear-powered submarines are shown on the ways at Electric Boat Division, General Dynamics Corp., Groton, Connecticut.

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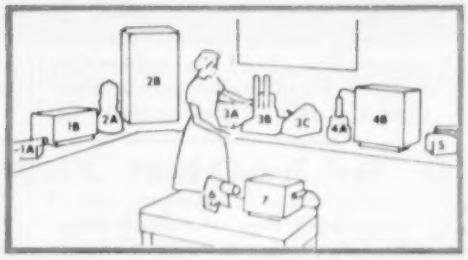
2A Model DS5-5 Scintillation Well Counter with exclusive "scaler-spectrometer" circuit and **2B** Model 1820 Recording Spectrometer for automatic quantitative energy separation of gamma-ray spectra.

3A Model 183B Count-O-Matic Binary Scaler, **3B** Model C110B Automatic Sample Changer with Model D47 Gas Flow Counter, and **3C** Model C111B Printing Timer for completely automatic changing, counting, and recording of as many as 35 soft beta emitting radioactive samples.



4A Model 3054 Manual Sample Changer with Model DS5 Scintillation Detector which features interchangeable alpha, beta, or gamma sensitive crystals connected to Nuclear-Chicago's finest scaler, the **4B** Model 192A Ultrascaler. Model 192A features decade scale of 10,000, one millivolt sensitivity, and precision automatic circuitry.

5 Model 2612P Portable Survey Meter contains a 1.4 mg/cm² thin window G-M tube for surveying for alpha, beta, or gamma contamination up to 20 milliroentgens per hour.

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7 Model 1620A-S Analytical Count Rate Meter offers a wide choice of full scale ranges, four time constants, wide range high voltage supply. It is shown with a Model D34 thin window G-M tube and P11 probe for continuous monitoring or analytical radioactivity determinations.

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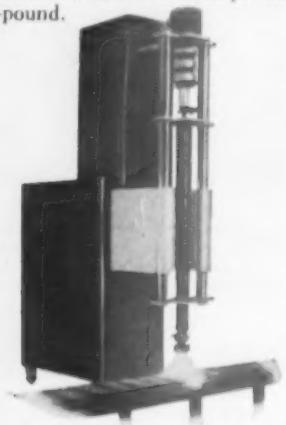
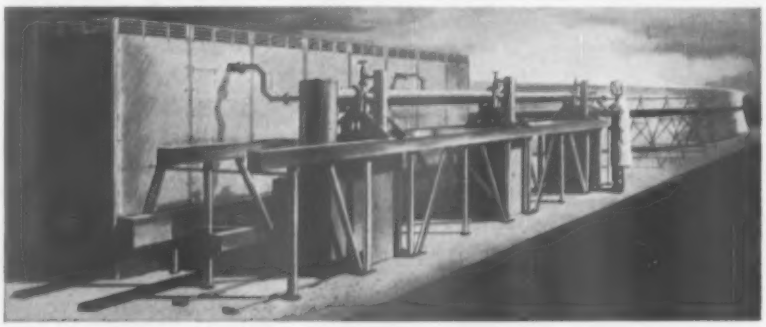


2-10 Mev, 4 kilowatt ARCO Mark 1-F4 Linear Accelerator will penetrate 1¼ inches from one side, provides electrons, x-rays and neutrons for research versatility.

The ARCO Mark 1-F4 Accelerator, designed for research and limited radiation processing, exemplifies ARCO techniques. The Mark 1-F4 delivers 4 kilowatts of 6 Mev electrons; for research use, beam energy can be varied from 2 to 10 Mev.



ARCO Building 20 Mev Linear Accelerator for M.I.T.—Harvard Synchrotron

A 20 Mev linear accelerator injector for the 6 Bev M.I.T.-Harvard synchrotron is now under construction by Applied Radiation Corporation.

The new ARCO accelerator provides 5 megawatts peak beam power, equalled by only a few accelerators in the world. It will allow the big M.I.T.-Harvard electron synchrotron to provide beam currents at an energy 6 times higher than today possible. To achieve high beam trapping efficiency required for this level of operation, unusually precise control of beam energy and frequency is mandatory.

ARCO's exclusive waveguide design permits frequency control within less than ± 0.1% at 2,855 MC. Over 0.21 amperes beam current are within an energy interval of 2 Mev and have less than $\pm 3 \times 10^{-3}$ radians angular divergence. Except for these unusually demanding requirements, the new ARCO accelerator is similar to other high energy ARCO machines already sold for physics research.

In common with other ARCO machines, the M.I.T.-Harvard accelerator embodies a number of significant design innovations. All organic materials are eliminated from the vacuum system, and the entire accelerator from electron gun to output beam analyzer is baked at 400° C. ARCO engineers have found it practical to attain operating vacuums better than 10^{-7} mm. Hg. without cold traps.

Massachusetts Institute of Technology and Harvard scientists will use the synchrotron to study proton and anti-proton pairs, strange new mesons and hyperons, electron structure and for studies involving pions, muons and higher energy nucleons.

Available Now

Unlike radioactive isotopes, ARCO linear accelerators are available today. Built to widely varying beam requirements, ARCO accelerators are excellent for applications as diverse as sterilizing surgical dressings, research in food preservation and large volume chemical processing.

Applied Radiation Corporation specializes in the development and manufacture of linear electron accelerators. Service Irradiation Centers at Walnut Creek, California, and soon at Rockford, Illinois, make linear accelerators available for experimental and limited commercial irradiations. Let us help you investigate radiation processing. Write for technical literature describing Applied Radiation's accelerators and service facilities.

*ARCO accelerators are available with either separate or integral klystron injection.

ARCO APPLIED RADIATION CORPORATION

High energy radiation for research and processing

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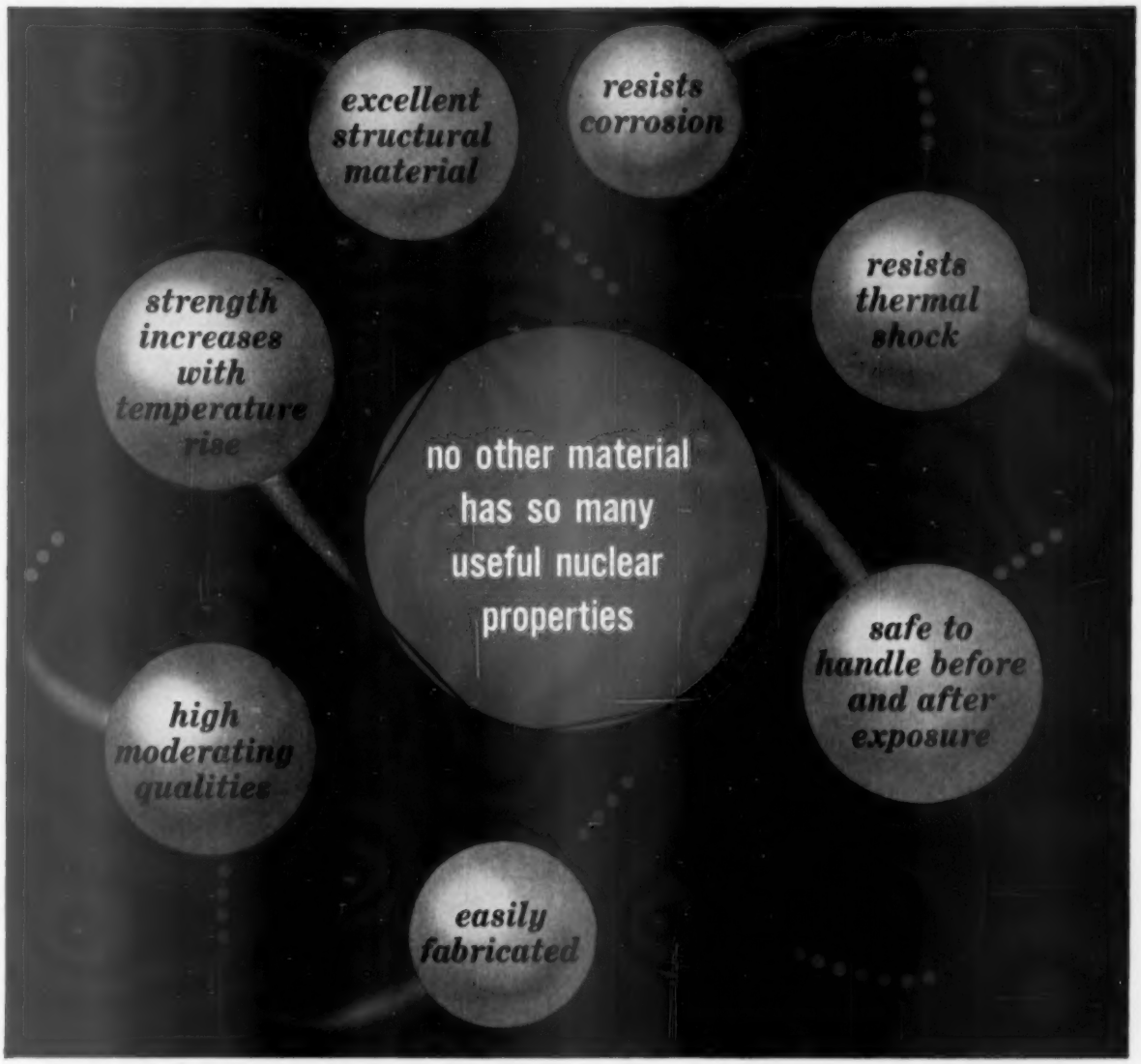
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resists corrosion
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strength increases with temperature rise
no other material has so many useful nuclear properties
safe to handle before and after exposure
high moderating qualities
easily fabricated

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NATIONAL NUCLEAR GRAPHITE
TRADE-MARK

Graphite is the material nuclear scientists call *surprisingly versatile.* Starting with the very first reactor, science has used this versatility to solve nuclear engineering problems.

"National" Nuclear Graphite was used in early reactors because of its excellent moderating properties and low neutron cross-section. Its low cost, safety, easy machinability and high refractory qualities also combine to make it an indispensable structural material. *Moreover, the addition of boron in low percentages makes graphite excellent for shielding.*

Whatever your needs . . . extreme purity, unique shapes or sizes, high density, large quantities, fast delivery . . . see National Carbon, the nation's most experienced graphite producer.

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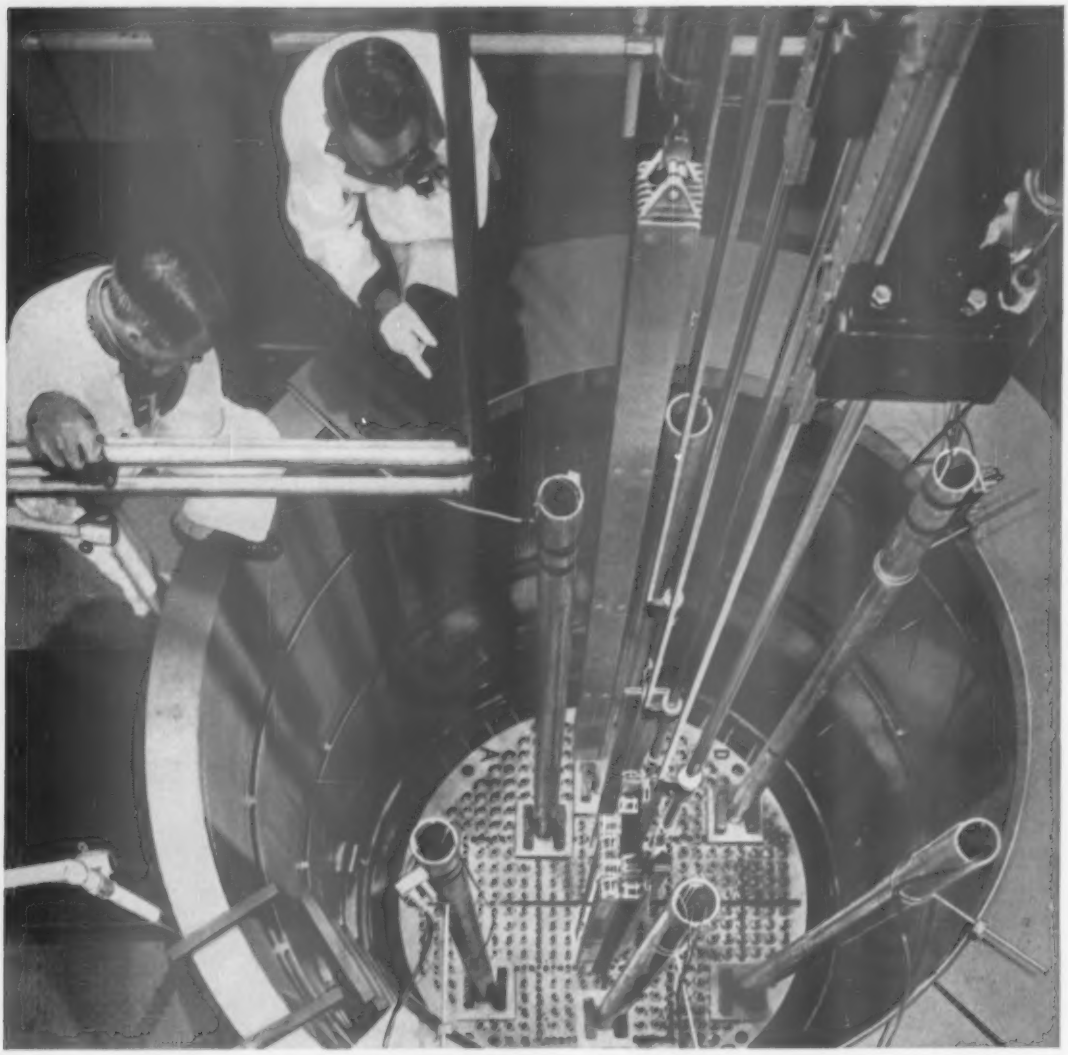


FORECASTING CORE PERFORMANCE

A nuclear power plant requires exact knowledge and control of the quantity and arrangement of the nuclear fuel. To determine precisely the operating nuclear characteristics and performance of B&W's full scale reactor cores, the company maintains a critical experiment laboratory at its specialized nuclear research facilities in Lynchburg, Va.

Critical experiments are conducted at virtually zero power, permitting economical, safe analysis of the proposed fuel cores and the gathering of nuclear data for their final design. Flux distributions in the reactor core are measured with foils of different elements which become radioactive under neutron bombardment.

In this way, the calculations of physicists and engineers can be confirmed or modified; optimum quantity and arrangement of fuel elements and control rods can be determined; the core's ultimate power distribution, safety and stability can be established; and a more accurate forecast of the conversion ratio and reactivity lifetime of the core is made possible.

This privately-financed critical test laboratory is just one example of B&W's investment in facilities, engineering, and research to put nuclear energy to work constructively and economically. The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

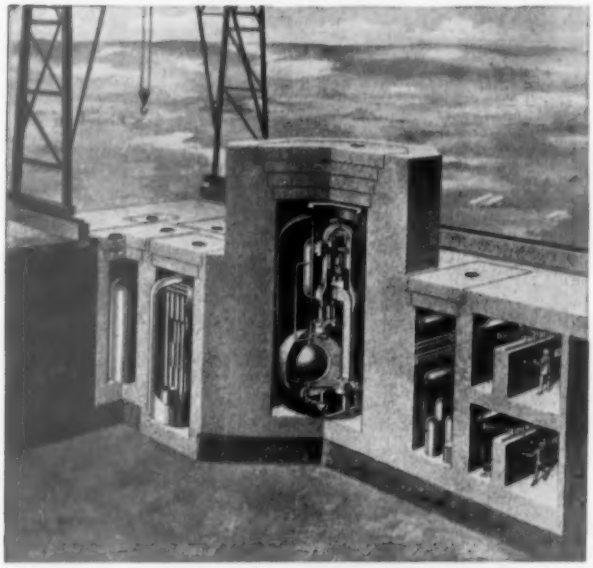
AE-46

BABCOCK & WILCOX

ATOMIC ENERGY DIVISION

HEAT ENGINEERING by FW

is pioneering tomorrow's LOW-COST ATOMIC POWER



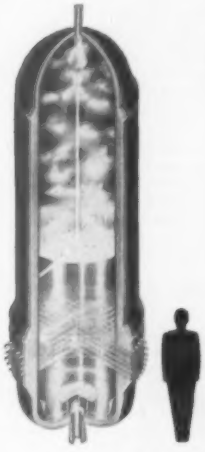
AQUEOUS HOMOGENEOUS BURNER REACTOR

Designed for the low and intermediate power range, the Aqueous Homogeneous Nuclear Power Plant offered by Foster Wheeler has these unique advantages: (1) inherent controlability and self regulation without the use of control rods, (2) minimum mechanical devices and moving parts, (3) continuous fuel addition and fission product removal, and (4) substantial savings in fuel processing costs.

CONVERTING heat from nuclear energy into electric power is heat engineering's newest and most challenging opportunity. From the very beginning, Foster Wheeler engineers have been engaged in development of the nuclear energy program — integrating over 50 years experience in heat-transfer equipment with nuclear engineering.

Working in close cooperation with the Atomic Energy Commission, large utilities and industrial companies, Foster Wheeler has pioneered in the design and development of nuclear reactors and major components for atomic power plants. FW nuclear equipment completed or under construction includes solid fuel tank-type research reactors, steam generators and pressurizers for America's first full-scale atomic power plant, steam generators for the first nuclear powered submarine, reactor vessel and steam generators for shipboard reactor prototype, equipment for test loops for liquid-metal fuel reactor systems, and separately fired superheaters for the first atomic power plant to operate with superheated steam.

With this background, a large staff of highly trained personnel, and the most modern fabricating facilities in three large plants, Foster Wheeler is well fitted to serve in the economical application of nuclear energy.



PRESSURIZER. This 300 cu ft pressurizer, designed and built by Foster Wheeler for America's first full-scale atomic power plant, will be used for initial raising of the coolant system pressure as well as to control pressure during operation. Designed for 2500 psig pressure at 675 F, it is 18 ft high and contains 342 electric immersion heaters.

STEAM GENERATORS. The heat-exchange steam generator during final assembly at a Foster Wheeler Plant, is one of two identical units installed at America's first commercial atomic power plant. Each unit will convert heat from the pressurized water reactor to 600 psia steam for driving the turbo generator.

SEPARATELY FIRED SUPERHEATERS. Two oil-fired superheaters by Foster Wheeler will superheat saturated steam from a pressurized water reactor from 447F to 1000F, at a large Eastern atomic power plant. Each unit has a capacity of 1,075,000 lb/hr at 410 psia. Addition of the superheat cycle raised plant capacity from 163,000 kw to 275,000 kw, reducing plant cost by about $95 per kw.

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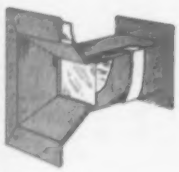
OFFERS YOU ABSOLUTE RADIATION PROTECTION

Now, from Ameray, a complete line of radiation protection products and services to fill both your standard and custom requirements. Everything in radiation shielding, from protective windows of zinc bromide-to fume hoods-to high density bricks-to complete reactor shielding can be obtained from Ameray in a minimum of time and with maximum economy . . . because Ameray's long experience in the design, development, and installation of nuclear products eliminates costly fabrications and insures the right design for your specific requirements. Fifty years of combined experience of America's engineering-production team can fill any of your industrial or medical shielding requirements easily and quickly. Contact Ameray; your requirements will be translated into protective shielding suited to your specifications.



LEAD GLASS WINDOWS

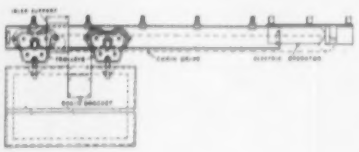
Ameray's lead glass windows are custom-designed for every application and can be produced in any size or configuration . . . with either Ameray 3.2 density lead glass or Ameray 6.2 density lead glass.

LEAD-LINED FUME HOODS

As a substantial aid to safe handling of all types of radioactive substances, the Ameray lead-lined fume hood is constructed with a sturdy steel frame and stainless steel interior and exterior facings.

PROTECTIVE LEAD BRICKS AND BLOCKS

If you require lead bricks for constructing portable barriers or high density blocks for shielding enclosures, Ameray can supply you with the proper sizes, shapes and densities in materials to your specifications.



MEDICAL REACTOR OR HOT CELL DOORS

Ameray's steel framed lead doors with complete electrical systems and appropriate hardware will be designed and fabricated to your specifications. The unit pictured is a seven inch lead door weighing 18,000 lbs.

PORTABLE LEAD CONTAINERS

The shipping or storing of gamma ray emitters, including spent fuel elements, is efficiently accommodated with Ameray's lead lined, steel containers fabricated to your requirements. Water cooled where required.

ZINC BROMIDE AND WATER-FILLED WINDOWS

Zinc bromide windows, by Ameray, offer excellent optical properties and superior protective qualities. Their flexibility of design enable zinc bromide windows to be manufactured to meet any vision and shielding requirements.

SEND FOR YOUR COPY OF AMERAY'S NEW CATALOGUE #55 ON DEPENDABLE "SAFETY-ENGINEERED" NUCLEAR SHIELDING PRODUCTS. X-RAY PROTECTION? ASK FOR CATALOGUE #22.

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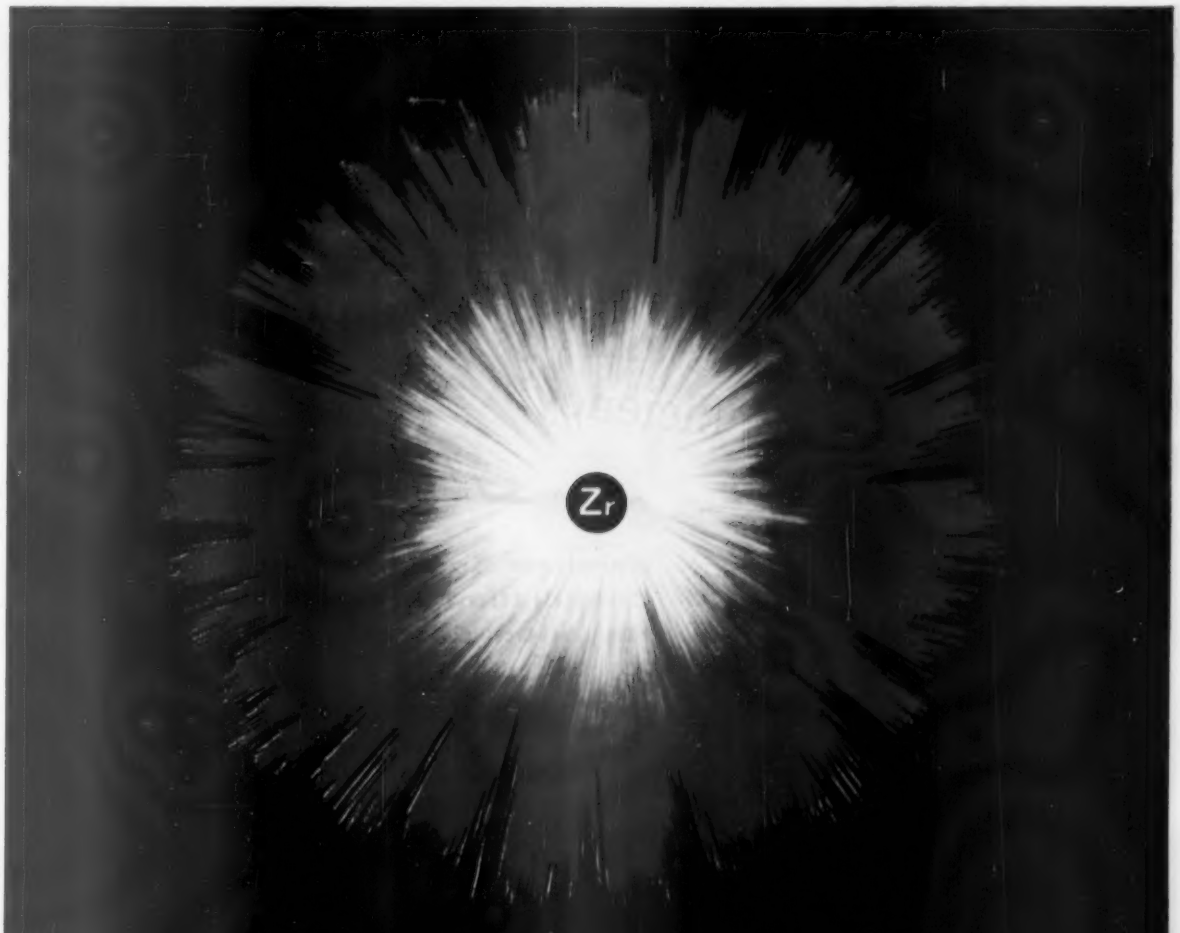

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New Oregon Plant Assures Immediate Delivery of High-Purity Sponge

A reliable source for reactor or commercial grade ZIRCONIUM . . . that will give you on-time deliveries.

A large scale supplier to the AEC, Wah Chang Corporation is now ready to fill **all** your ZIRCONIUM needs **as they occur** . . . and at competitive prices.

The quality of WCC ZIRCONIUM is entrusted to experienced personnel whose skill has guided the development of ZIRCONIUM as a commercial metal. In addition, WCC controls every manufacturing process from sand to sponge.

That's why WCC ZIRCONIUM has the consistent properties needed to fulfill exacting applications . . . including: exceptional ductility for ease of compacting and rolling . . . excellent corrosion resistance.

SEND FOR COMPLETE INFORMATION, PRICES OR TECHNICAL ASSISTANCE.

More WCC Metals are on the way . . . look for them.

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BRINGING TOMORROW CLOSER WITH NEW METALS

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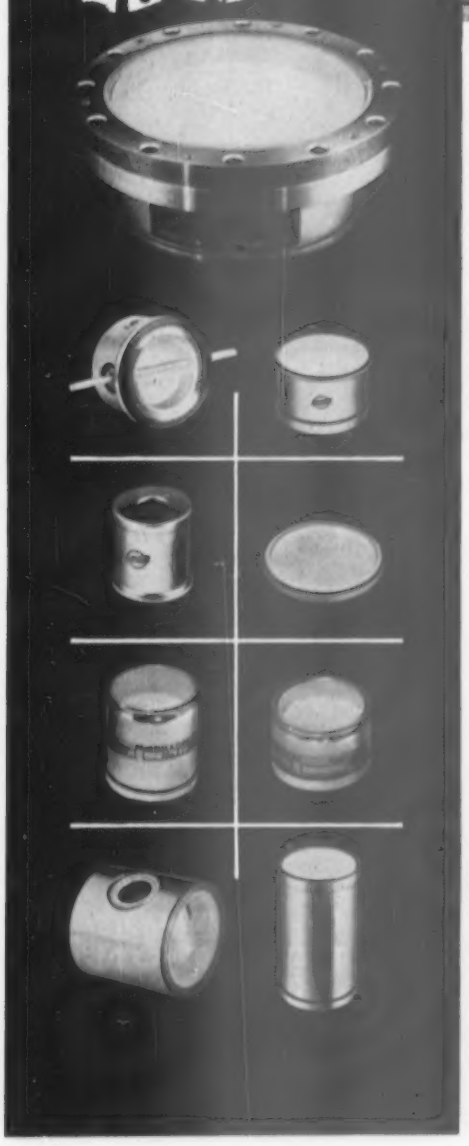
1. "Harshaw Quality" inherent in each Harshaw-made crystal. 2. No ultra violet light absorbing impurities. 3. Highest light transmission. 4. Maximum energy conversion efficiency.



Harshaw Sodium Iodide (Thallium) Scintillation Crystals for gamma radiation detection instruments

"Harshaw Quality" . . .
inherent in each Harshaw-made crystal

The high purity, clarity, and proper activation of Harshaw Crystals are a natural result of our long pioneering experience in the delicate art of crystal growing.

Harshaw Purity means light absorbing impurities are reduced to infinitesimal traces.

Harshaw Clarity gives highest possible transmission of the crystal's own emitted light.

Harshaw Activation means the optimum thallium concentration ensuring maximum energy conversion.

Our crystals are normally supplied hermetically sealed in aluminum containers engineered to secure maximum light collection. We will custom design these units to fit your specific requirements. Harshaw crystals are currently used in nuclear physics research, well logging, uranium prospecting, medical research, and industrial process and product control.

No need to specify "Harshaw Quality" . . . you get it automatically when you order Harshaw Crystals. We encourage requests for technical assistance. Prices, specifications, or other information will be sent in answer to your inquiry.

HARSHAW

OTHER HARSHAW SCINTILLATION CRYSTALS AVAILABLE IN THE FOLLOWING FORMS:
Potassium Iodide (Tl) • Cesium Iodide (Tl) • Cesium Bromide (Tl)
Anthracene • Stilbene • Naphthalene
Lithium Iodide (Eu) for neutron detection • Sodium Iodide (rough cut blanks)

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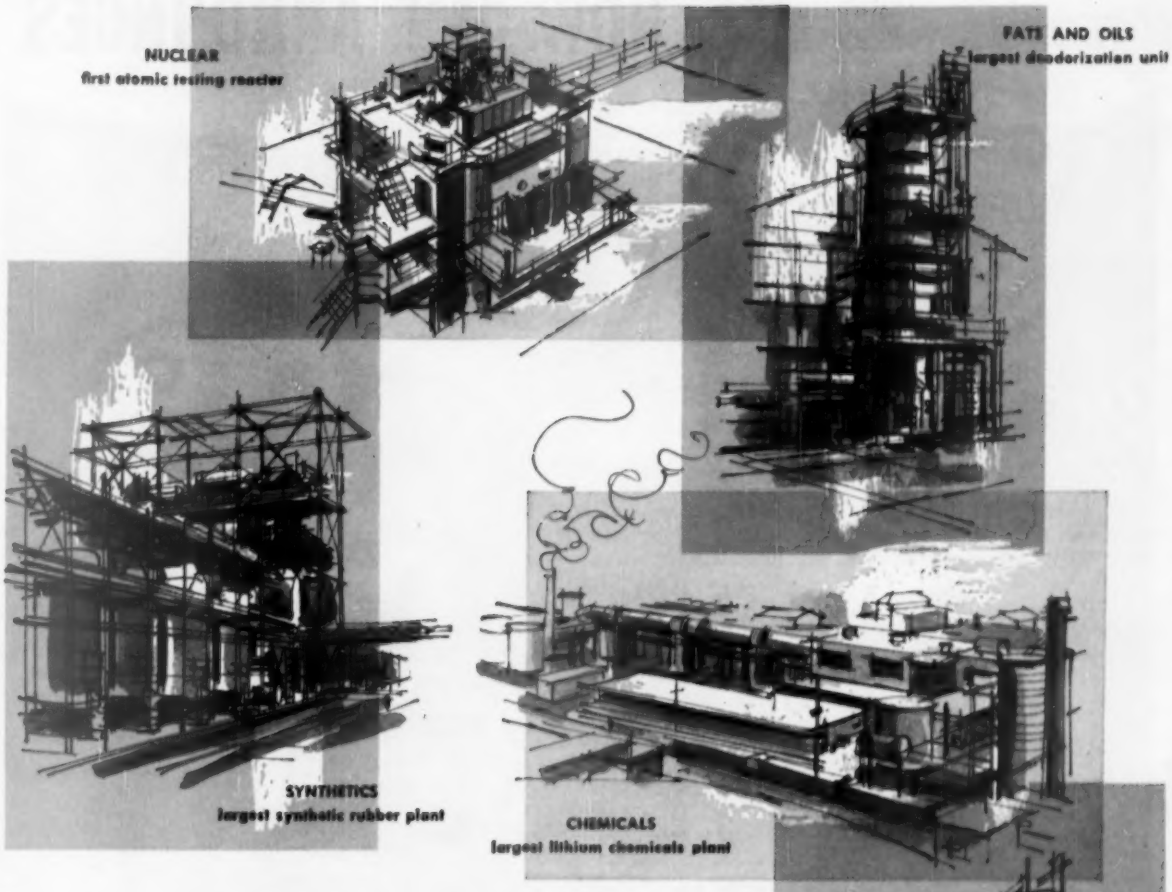

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Regardless of the size or scope of your next project, the selection of the engineer-contractor remains a most critical decision. Pace setting projects provide one of the best proofs of the quality of creative resources and the extent of construction experience.

In offering a complete service that ranges from preliminary surveys, engineering and procurement to construction and initial operation, Blaw-Knox qualifications consistently meet the processing industry's most rigid requirements.

To see how this background can help your plans for process development, plant erection or modernization, contact our engineers for a preliminary discussion.

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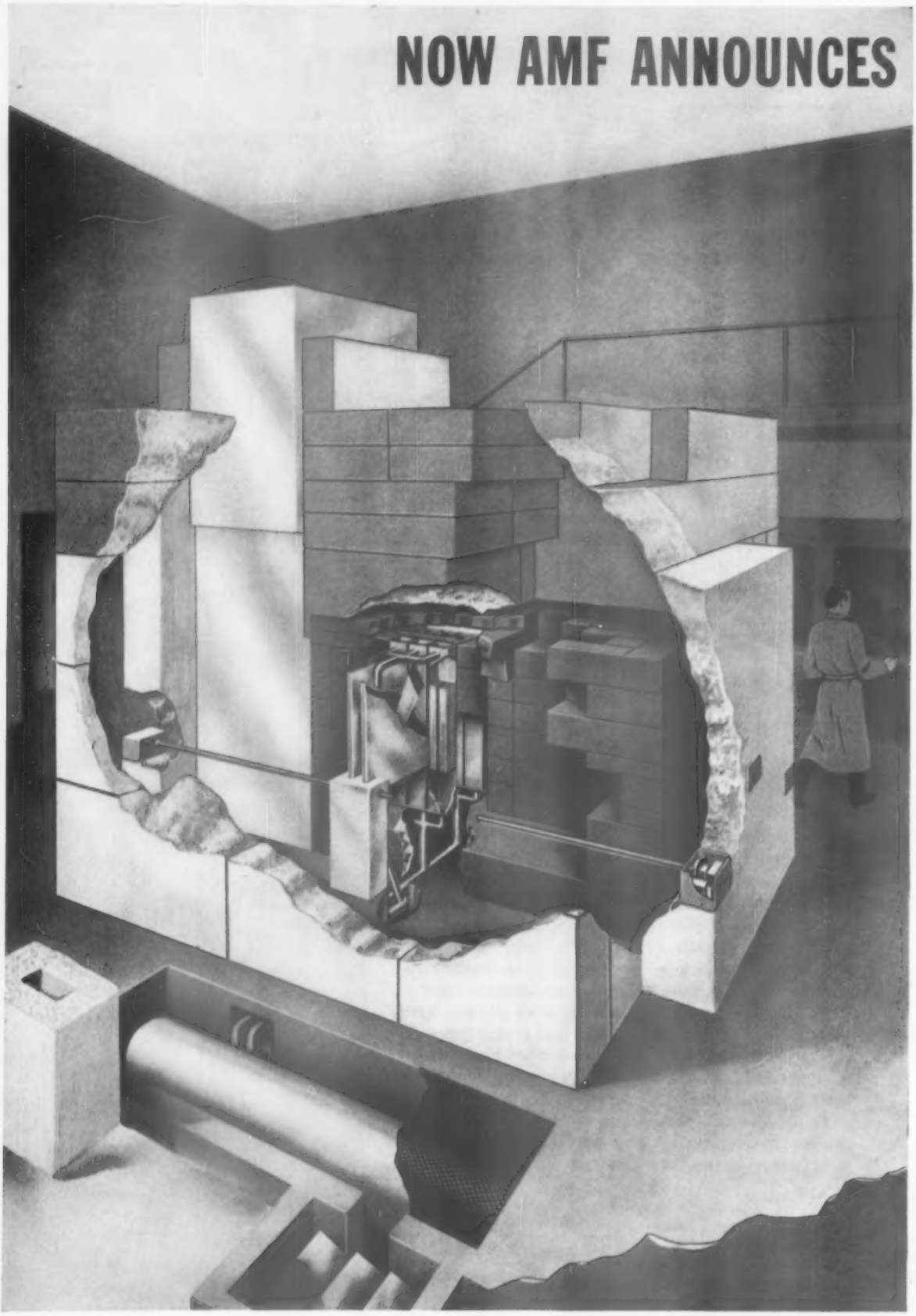
NOW AMF ANNOUNCES

a new training reactor—the AMF-GNE Educator

AMF ATOMICS, the world's leader in research reactor design and construction, has joined forces with Dr. Walter H. Zinn and his General Nuclear Engineering Corporation to provide a new and improved version of the Argonaut-type training reactor.

EDUCATOR TRAINING REACTOR

TYPE
Thermal heterogeneous

POWER
Operating power 10 KW thermal, continuous

FLUX
At center 10^{11} neutrons/sq cm/sec

FUEL
Uranium-aluminum alloy arranged in 24 bundles and containing approximately 3.8 kg of U-235 in 20% enriched fuel

MODERATOR
Graphite and light water

CORE
5 ft. x 5 ft. x 4 ft. rectangular prism of graphite containing 6 light-water-filled aluminum fuel boxes

COOLANT
Light water pumped into fuel boxes with gravity feed to heat exchanger and storage tank

CONTROL
4 swinging-arm type blades
Light water moderator quick dump

SHIELDING
5 ft. concrete block

This new AMF-GNE Training Reactor offers universities and educational systems everywhere a low-cost facility that is both unusually safe and highly flexible in application. Experience-dictated modifications and improvements made on the Argonaut-type design by General Nuclear Engineering Corporation, coupled with the reactor engineering and construction experience of AMF, has made the Educator the most advanced of all reactors for university training.

Essentially a water-and graphite-moderated, graphite-reflected reactor, the Educator has been designed for graduate and undergraduate studies and industrial training. It offers a comprehensive facility for training in reactor physics and engineering, as well as in nuclear physics, radiochemistry, radiobiology, and related fields.

Safety—Since the reactor is designed to operate at the low power level of 10 kw, there is a minimum of excess reactivity, and the amount of contained fission products is small. There is no credible way in which the fission products can escape the fuel elements. The reactor is, therefore, perfectly suited for a university campus installation.

Since the core is based upon the design developed in the Borax experiments, the reactor is inherently safe. Proper control of the fuel loading of the reactor is all that is necessary to insure that no accidental mismanagement will result in the release of fission products from the fuel plates.

Low Cost—The simplicity and small size of the Educator permits installation in an existing building, without requiring any other construction. Generally speaking, campus locations should be possible, and the reactor itself is highly adaptable to a variety of installation requirements.

Versatility—The AMF-GNE Educator is designed for continuous operation at 10 kw, giving a thermal neutron flux of 10^{11} neutrons per sq. cm/sec. Horizontal and vertical thimbles, a thermal column, and a large water tank providing flexible irradiation space are features of the installation. Possible experiments include control rod calibration, neutron optics, neutron flux determination, chemical analysis by activation, irradiation of biological materials, and a wide range of other reactor and irradiation studies.

Assistance Program—In addition to the actual manufacture and installation of the reactor, AMF and GNE can assist in any or all phases of your nuclear energy training program, including:

1. Site investigation
2. Preparation of hazards summary report
3. Application for license, grants, fuel processing and fabrication
4. Reactor start-up, calibration, and test
5. Operator training at an existing facility
6. Suggested reactor experiments
7. Safety and health physics program

If you are now, or plan soon to be, engaged in nuclear physics and engineering training, be sure to discuss your plans with AMF ATOMICS. You'll find AMF's unequalled reactor experience the perfect partner to your program. For more information on any phase of AMF's complete nuclear reactor facilities, from design through operation and training, write us today.

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A Division of AMERICAN MACHINE & FOUNDRY COMPANY
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AR PURCHASING

Annual BUYERS' GUIDE ISSUE to contain comprehensive product information

THE ONE! THE ONLY! THE ORIGINAL Buyers' Guide designed *specifically* to fulfill the needs of the *expanding* nuclear industry.

To *verify* the Buyers' Guide accuracy, NUCLEONICS staff questionnaires the *entire* nuclear industry *every* year . . . the forthcoming issue will feature alphabetical listings for nearly 1,600 manufacturers of nuclear and allied products . . . all cross-referenced for easy location. Product listings are free and advertisers' listings are run in bold type and contain the page number of their advertisement.

For one *full* year this single issue remains the leading source for catalog-type information . . . tailored to the *specialized requirements* of nuclear purchasing. And this year the NUCLEONICS Buyers' Guide will reach more than 17,000 paid subscribers, the men who influence the purchasing of *your* products.

Give *both* your prospects and customers the full details of your latest developments . . . get your product selling message in the November Buyers' Guide Issue of NUCLEONICS.

Salesbuilding idea: insert your catalog in this issue and give them maximum buying information!

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ONE OF NUCLEONICS BIG 3 . . . FOR FALL '57

YTTRIUM

Availability of high purity yttrium and rare earth oxides

A report by LINDSAY

Only three years ago, most high purity rare earths were little more than laboratory curiosities.

Today they are extensively used for an amazing variety of chemical and industrial applications.

What happened? Lindsay technicians pioneered the first commercially installed ion exchange unit for the production of separated rare earths. The process was patterned after techniques developed by Doctors Spedding and Powell of the Institute for Atomic Research at Ames, Iowa.

Lindsay's pilot plant rare earth ion exchange installation had 40 six-inch columns. This unit made purified rare earths available to industry for the first time in practical, even though still limited, quantities.

The response from industry was so enthusiastic, we were forced to expand our ion exchange facilities rapidly. Today we have in continuous operation more than 100 columns with large production units of eighteen-inch and sixty-inch diameters.

With our larger production facilities, we are now making prompt shipments of high purity yttrium and rare earth oxides in quantities from a gram to hundreds of pounds.

TYPICAL MAXIMUM IMPURITIES IN LINDSAY PURIFIED RARE EARTH AND YTTRIUM OXIDES

ATOMIC NO.	OXIDE	CODE	PURITY	% RARE EARTH MAXIMUM IMPURITIES AS OXIDES
57	La_2O_3. LANTHANUM OXIDE	528	99.99	0.01 Pr, 0.001 Ce.
		529	99.997	0.0025 Pr, 0.0005 others
58	CeO_2. CERIC OXIDE	215	99.8	0.2 (largely La + Pr + Nd).
		216	99.9	0.1 (largely La + Pr + Nd).
59	Pr_6O_{11}. PRASEODYMIUM OXIDE	726	99	1 La + Nd + smaller amounts of Ce and Sm.
		729.9	99.9	0.1 Ce + Nd.
60	Nd_2O_3. NEODYMIUM OXIDE	628	95	1-4 Pr, 1-4 Sm, 0.5-1 others.
		629	99	0.1-0.4 Pr + 0.1-0.4 Sm + 0.5 others.
		629.9	99.9	0.1 (largely Pr + Sm).
62	Sm_2O_3. SAMARIUM OXIDE	822	99	0.2-0.7 Gd, 0.2-0.6 Eu, and smaller amounts of others.
		823	99.9	0.1 (largely Nd + Gd + Eu).
63	Eu_2O_3. EUROPIUM OXIDE	1012	98-99	1-2 Sm + smaller amounts of Nd + Gd + others.
		1011	99.8	0.2 (largely Sm + Gd + Nd).
64	Gd_2O_3. GADOLINIUM OXIDE	928.9	99	1 Sm + Eu + trace Tb.
		929.9	99.9	0.1 Sm + Eu + trace Tb.
65	Tb_4O_7. TERBIUM OXIDE	1803	99	1 Gd + Dy + Y.
		1805	99.9	0.1 Gd + Dy + Y.
66	Dy_2O_3. DYSPROSIUM OXIDE	1703	99	1 (largely Ho + Y + Tb + small amounts of others).
		1705	99.9	0.1 Ho + Y + traces of others.
67	Ho_2O_3. HOLMIUM OXIDE	1603	99	1 (largely Er + Dy + small amounts of others).
		1605	99.9	0.1 Er + Dy + traces of others.
68	Er_2O_3. ERBIUM OXIDE	1303	99	1 Ho + Dy + traces Yb and Y.
		1305	99.9	0.1 Ho + Tm.
69	Tm_2O_3. THULIUM OXIDE	1405	99.9	0.1 Er + Yb + trace Lu.
		1403	99	1 Er + Yb + trace Lu
70	Yb_2O_3. YTTERBIUM OXIDE	1201	99	1 Er + Tm + trace Lu.
		1202	99.9	0.1 Tm + trace Lu + Er.
71	Lu_2O_3. LUTETIUM OXIDE	1503	99	1 Yb + Tm + traces of others.
		1505	99.9	0.1 Yb + Tm + traces of others
39	Y_2O_3. YTTRIUM OXIDE	1112	99	1 Dy + Gd + traces Tb and others.
		1115	99.9	0.1 Dy + Gd + traces Tb
		1116	99.9+	Approx. 0.05 Dy + Gd.

COSTS GREATLY REDUCED

Of course, as production of purified rare earths increased, costs came down. For example, only three years ago Terbium Oxide cost $500 a gram. Today you can obtain moderate size lots at less than $3 a gram.

Now that you know these high purity oxides are so readily available and the cost so remarkably low, what are *you* waiting for?

Rare earths, in purities up to 99.99%, have captured the interest and imagination of scientists in many industries as valuable new tools for the improvement of processes and products.

Your research, product development and production people should investigate the possibilities of these materials. Our bulletin "Purified Rare Earth and Yttrium Oxides" will give you detailed information and prices.

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LINDSAY CHEMICAL COMPANY

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Perhaps we have already solved your nuclear handling problem

Hot cell handling problems have been met—and solved—for nearly a decade by General Mills engineers. Our fund of nuclear handling know-how is available to you. Consultation in the early planning stages of your installation could save you time and money—and result in more efficient operation.

Whether your requirement is a standard General Mills Mechanical Arm or special equipment—or if you are wondering which—contact our Nuclear Products Department, 1620 Central Avenue, Minneapolis 13, Minnesota. The phone is STerling 9-8811.

MECHANICAL DIVISION

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Mechanical Systems and Components for Nuclear Reactors

United

has integrated facilities for

Research · Design · Prototype · Test · Manufacture

Preparing to test a submarine reactor Control Rod Drive Mechanism at UNITED'S TEST FACILITY

United can provide assistance on your reactor programs

United's Atomic Power Department is ready to aid you with the design and development of control rod drive mechanisms, fuel handling systems, and special remote handling devices for nuclear reactors.

For over 50 years United has pioneered in the design, development, and manufacture of highly specialized yet diversified machines and equipment. For the past 6 years, Atomic Power Department personnel have been engaged in projects in the nuclear field, thus obtaining additional valuable experience and know-how that will contribute to the solution of your problems.

For further information, contact: **United**

SHOE MACHINERY CORPORATION

Atomic Power Department

Balch St., Beverly, Mass.

NUCLEAR NEWSLETTER FROM WORTHINGTON

As a result of extremely successful development work begun some 3½ years ago, **Worthington is now producing canned rotor pumps for Navy shipboard use.** Units circulate primary coolant in the reactor systems of atomic submarines and the frigate prototype. These motor driven units operate at 3,500 rpm and feature a number of significant design developments.

Another successful development job was performed recently for the **Aircraft Nuclear Propulsion Program.** Worthington's contribution included the design and model testing of pumps for the primary circuit.

Currently Worthington is continuing design and development work on **water-lubricated bearings and special seals** for application in the primary circuits of nuclear power generation plants.

The nuclear field certainly involves a wide variety of equipment. Almost all of Worthington's broad line of power products—pumps, compressors, turbines, engines power transmission components—are used by this industry. **Worthington has already delivered special modifications of many products for use in special extraction processes.**

Worthington opens for business on packaged secondary circuits! Design and study work has been finished for compete secondary circuits of nuclear plants up to 12,500 kw. Worthington is one of the few manufacturers in a position to take complete responsibility for design and performance of the secondary circuit. They can also supply all major equipment involved, from their own standard manufacture. Nuclear experts forecast a big export market for these plants in the 5 to 10,000 kw range with estimates as high as 1,500,000 kw of capacity needed in the next few years.... Anyone interested?

Worthington is alerting its overseas organization to the coming boom in the nuclear market. With 121 distributors and 11 manufacturing plants around the world, Worthington will be a strong factor in this export market.

Reactor builders have asked Worthington to participate in informal study groups to arrive at proposals for the development of new equipment for reactor systems. Worthington finds these groups one of the best

INSERT IS PERFORATED. Tear out for reference

ways of keeping abreast of the fast changing industry.

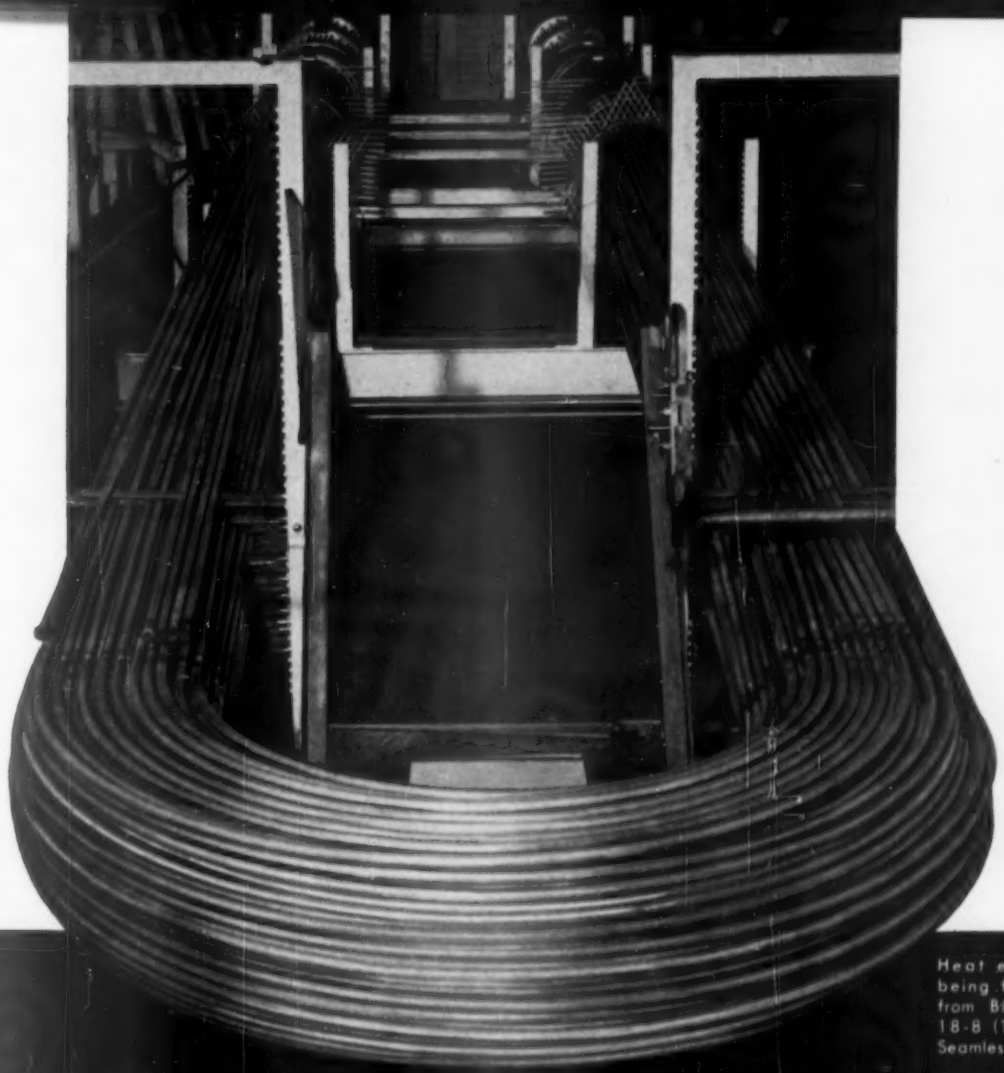
Considerable progress is being made in the development of designs for **high temperature liquid metal pumps.**

Interesting facts turned up in a recent Worthington survey in the Nuclear industry:

- Canned rotor pumps are given a 50/50 chance for acceptance with liquid metals such as sodium.
- Majority will consider controlled in-leakage pumps for water or water slurries.
- Immersed bearings will be satisfactory for water, but opinion is split on liquid metals.
- Most primary systems will be designed to eliminate valves, wherever possible, since this is a source of expense and trouble.
- Future pressure vessels may require welding positioners up to 100 tons to handle them.
- Gas cooled reactor closed cycle gas turbine systems will undoubtedly have their first application in the Marine field within 5 years.
- Water will be the coolant in most reactors built for power generation or ship propulsion in the next 5 to 10 years. The industry may then switch to slurries and liquid metals. Ultimate choice: gas cooled reactors.

M.7.2

Your inquiries are invited. Please write to R. H. Davis, Manager, Marine & Nuclear Energy Dept., Worthington Corporation, Harrison, N. J.



Heat exchanger being fabricated from B&W Croloy 18-8 (Type 304) Seamless Tubing.

B&W TUBULAR PRODUCTS FOR NUCLEAR APPLICATIONS

In nuclear applications there are many and various conditions which tubular products must meet. These problems may involve the metal of which the tube is produced, the dimensional accuracy of the tube, its uniformity and soundness, its surface finish and cleanliness or the ease with which it can be further fabricated.

Supplying tubular products for nuclear applications since its beginnings, and for all phases—from the refining and production of fissionable materials, through the generation of energy by various types of reactors and other uses of fissionable materials—has given B&W engineers the background to cope with practically any set of circumstances.

That is why B&W Tubular Products of such materials as zirconium down through the standard and special stainless and alloy steels and carbon steels have found wide use in heat exchangers, piping and structural and mechanical parts. A call to Mr. Tubes, your nearby B&W tube representative can help solve your tubular problems in the nuclear field. The Babcock & Wilcox Company, Tubular Products Division, Beaver Falls, Pa.

TA-7012-PN1

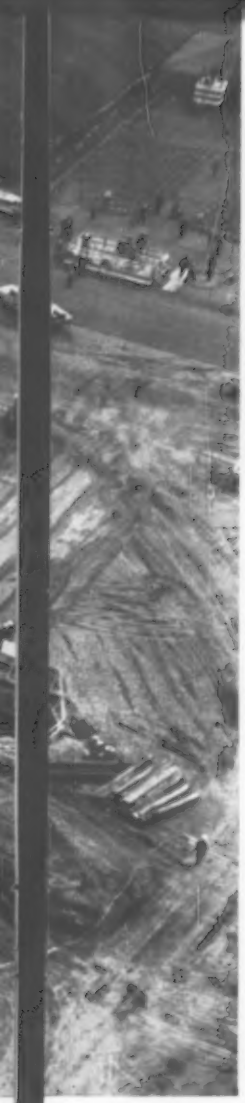
Seamless and welded tubular products, seamless welding fittings and forged steel flanges—in carbon, alloy, and stainless steels.

PROGRESS REPORT ON DRESDEN STATION

GENERAL ELECTRIC DUAL-CYCLE BOILING WATER REACTOR will be housed in 190-foot steel sphere on foundation already completed at Dresden site. Turbine building construction, lower left, is well under way.

DEVELOPMENTAL BOILING WATER REACTOR at General Electric Vallecitos Atomic Laboratory will furnish vital operational data to be used for Dresden Station. Turbine-generator for facility will be owned and operated by Pacific Gas and Electric Company.

REFUELING PROCEDURES AND EQUIPMENT DESIGN are studied in 54-foot-high refueling test tank in San Jose. Tank simulates reactor pressure vessel conditions, including heat and water-circulating factors.



Full-scale construction begins on world's largest all-nuclear power station

WORK ON GENERAL ELECTRIC-DESIGNED DRESDEN NUCLEAR POWER STATION MOVES AHEAD "ON SCHEDULE"

A milestone in atomic progress was passed June 12 with the start of major construction on Commonwealth Edison Company's Dresden Station. During brief ceremonies at the site one of the huge columns which will support the 190-foot sphere was swung into position and bolted into place by key officials.

Plant engineering for Dresden's dual-cycle boiling water reactor is over 55 percent complete. General Electric and the Bechtel Corporation (engineer-constructor) have let contracts to over 175 companies who are fabricating various parts of the plant.

General Electric is utilizing its development facilities at its Atomic Power Equipment Department in San Jose, California and its near-by Vallecitos Atomic Laboratory for the Dresden reactor. More than $31,000,000 has already been paid out or committed for materials and equipment.

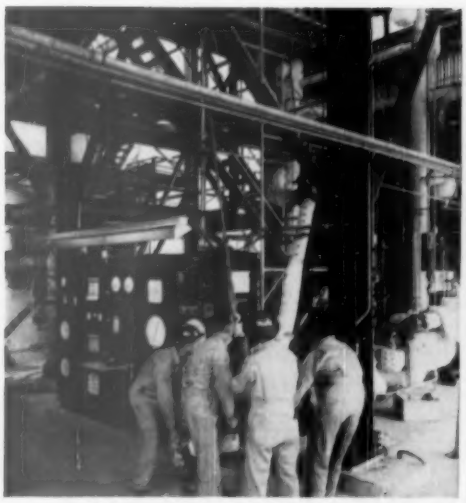
A pioneering spirit is being demonstrated at Dresden. Commonwealth Edison and General Electric, in co-operation with the Nuclear Power Group, Inc., have displayed industrial leadership in developing a new concept of power generation which will make the peacetime atom a working reality in the Chicago area by 1960. General Electric Co., Atomic Power Equipment Dept., San Jose, California.

For more information, write for bulletin GER-1301, Progress Report on Dresden Station, General Electric Company, Section 192-11, Schenectady, New York.

MEMBERS OF THE NUCLEAR POWER GROUP, INC.—American Gas & Electric Service Corp., Commonwealth Edison Company, Pacific Gas & Electric Company, Union Electric Company of Missouri, Illinois Power Company, Kansas City Power & Light Company, Bechtel Corp., Central Illinois Light Company.

Progress Is Our Most Important Product

GENERAL ELECTRIC



HEAT TRANSFER AND FLUID FLOW are tested in this special test loop designed for study of void distribution, steam slip, steam blanketing and heat transfer.

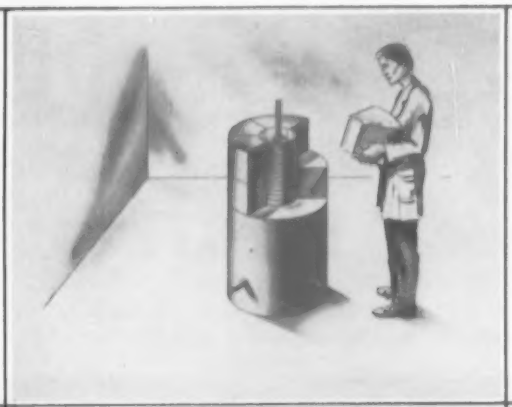
TWO-PHASE FLOW TEST mock-up of dual-cycle BWR steam system simulates coolant flow and steam void characteristics for this type reactor's coolant system.

CRITICAL EXPERIMENTS at Vallecitos Atomic Laboratory will be performed with Dresden core mock-up to study core configurations and fuel loadings.

Reactor Production Line...

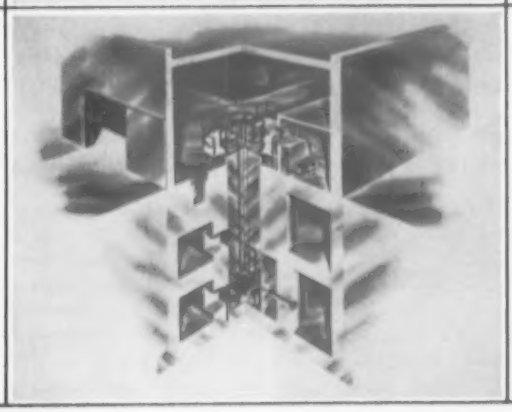
FIRST AGAIN – *Aerojet-General produced reactors, announce the from sub critical to multi-megawatt*

AGN 101 • SUB CRITICAL ASSEMBLY
0 POWER

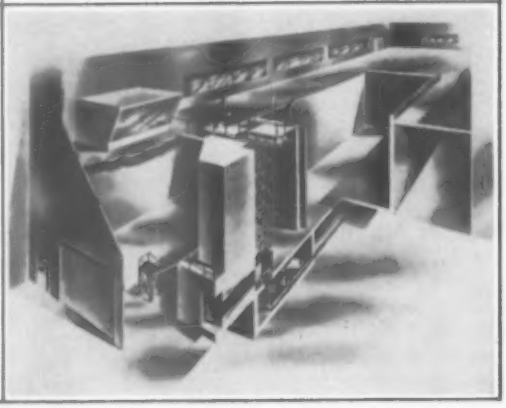


AGN 201 • PORTABLE TRAINING & RESEARCH REACTOR • TO 5 WATTS

AGN 501 • MEDICAL & RESEARCH REACTOR
TO 100 KILOWATTS



AGN 601 • SWIMMING POOL RESEARCH REACTOR • TO 10 MEGAWATTS

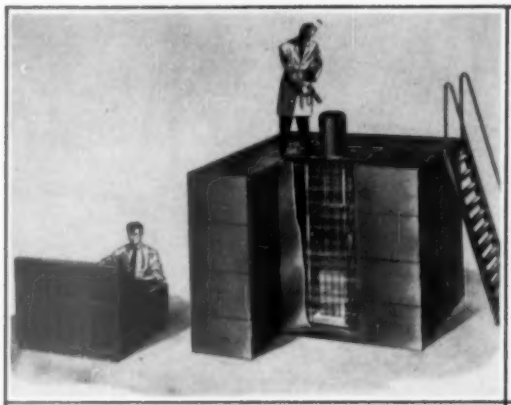


Aerojet-General Nucleonics

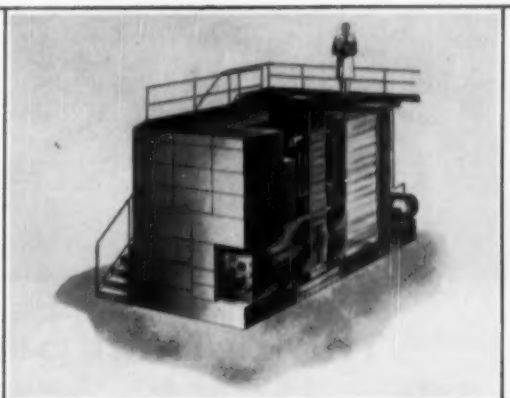
near San Francisco at SAN RAMON, CALIFORNIA

to Test and Training Area.

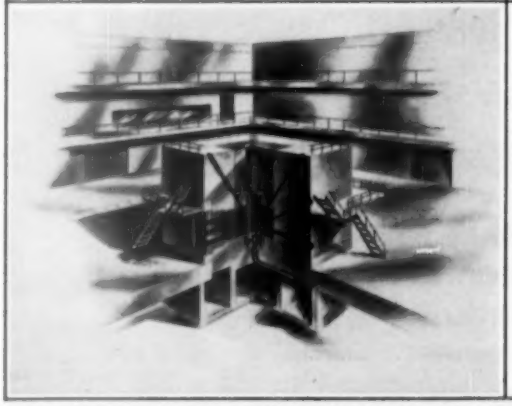
Nucleonics, the originators of mass world's first complete reactor line, research and power reactors- - - - -



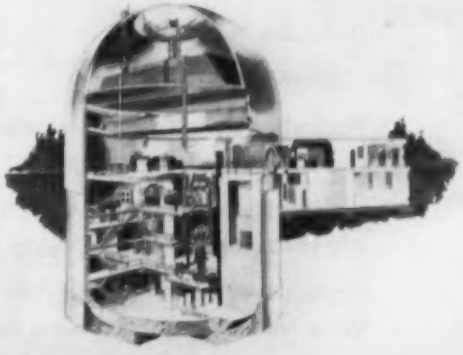
AGN 211 • PORTABLE SWIMMING POOL TRAINING & RESEARCH REACTOR • TO 100 WATTS



AGN 401 • PORTABLE TRAINING & RESEARCH REACTOR • TO 10 KILOWATTS



AGN 701 • TANK TYPE RESEARCH REACTOR MULTI-MEGAWATT

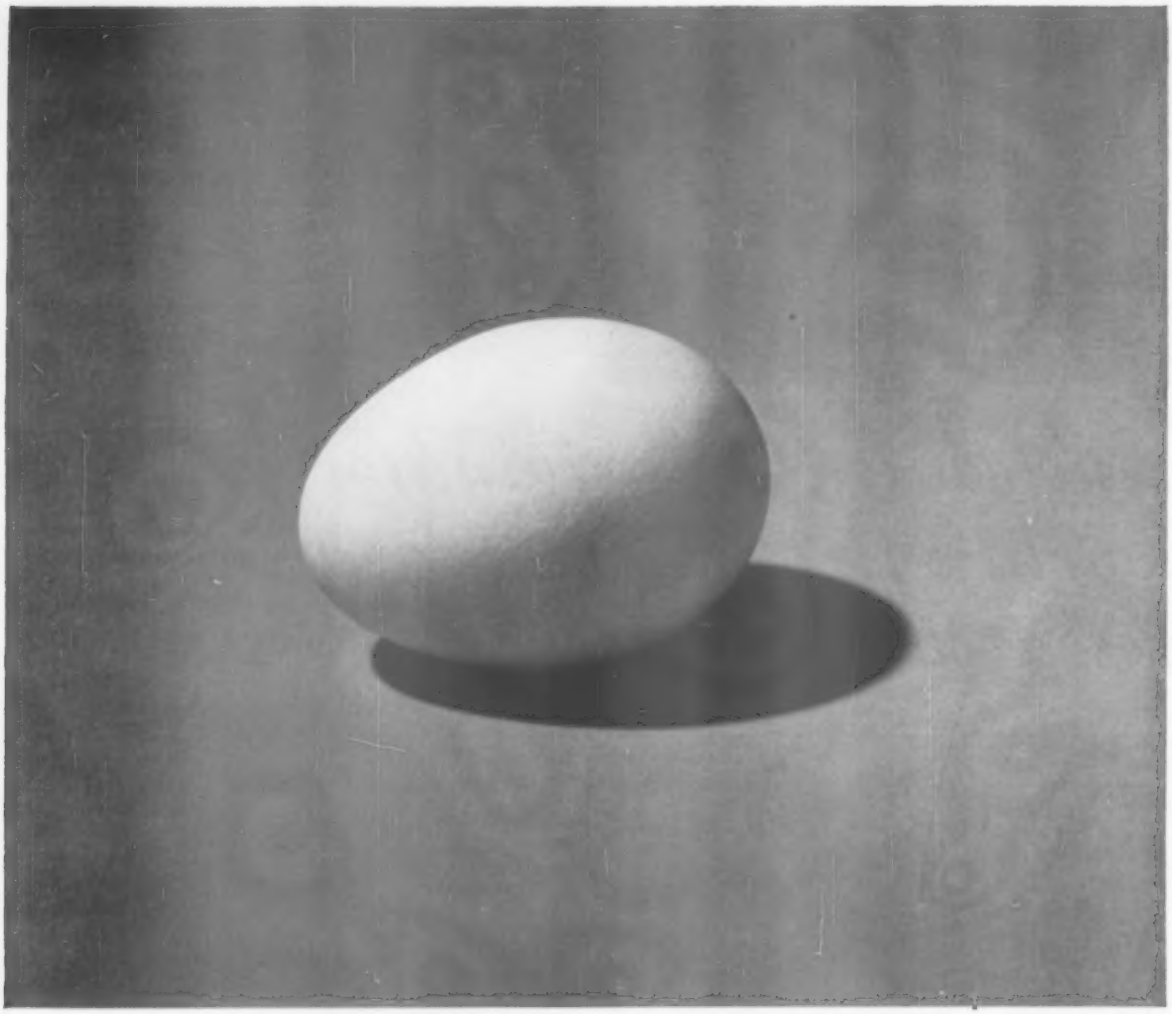


AGN 801 • BOILING WATER POWER REACTOR MULTI-MEGAWATT

AEROJET-GENERAL IS CURRENTLY ENGAGED IN THE GAS COOLED REACTOR EXPERIMENT—A CLASSIFIED PROJECT SPONSORED BY THE U.S. ATOMIC ENERGY COMMISSION.

a subsidiary of the Aerojet-General Corporation THE GENERAL TIRE

CABLE ADDRESS: AGNU • TELEPHONE VErnon 7-4267



The perfect package...

Simplicity in form . . .

Perfection in design . . .

Convenience indeed.

Nuclear Systems' complete radiation package offers economy and efficiency to our customers.

We provide equipment, instrumentation, training, facility design and sources of cobalt 60 up to 50,000 curies.

Applications are as diverse as the irradiation of foods, the polymerization of synthetic resins, and the synthesis of chemicals.

NUCLEAR SYSTEMS

A DIVISION OF THE BUDD COMPANY Philadelphia 32

Budd

NEW LOW PRICES FOR COBALT 60

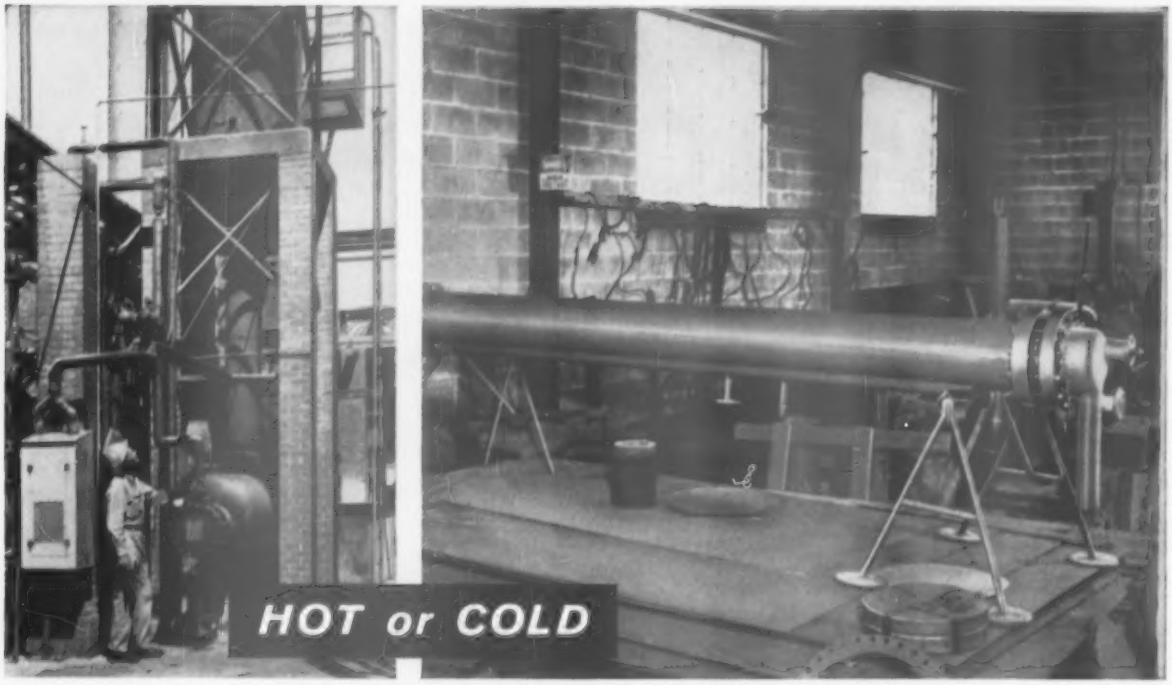
Nuclear Systems, a division of The Budd Company, announces the following reduced prices for Cobalt 60, effective for orders received after July 31, 1957.

	SPECIFIC ACTIVITY (curies per gram)		
CURIES	UP TO 25	25-40	OVER 40
1,000	$4,800	$6,100	$7,400
2,000	8,400	10,900	13,500
3,000	11,800	15,500	19,300
4,000	15,000	20,000	25,000
5,000	18,300	24,400	30,500
7,500	27,000	36,000	45,000
10,000	34,800	46,400	58,000
15,000	50,300	67,100	83,900
20,000	66,000	88,000	110,000
25,000	80,000	106,600	133,200

The prices given are for typical source strengths. Any other strength source will be quoted on request. All prices include encapsulation and installation in approved shield or remote handling device, whether of Nuclear Systems design and manufacture or not.

NUCLEAR SYSTEMS

A DIVISION OF THE BUDD COMPANY, Philadelphia 32



Hydrofluoric acid is re-concentrated to a strength of 90-92% in this regenerator. Acid is 280°F; 80 psi. Tower is lined with Monel nickel-copper alloy to resist severely corrosive environment. Shell and tubes of the steam reboiler are Monel as well.

Monel alloy internals resist corrosion by liquid HF produced in this condenser. HF stream passes through tube side, Freon through shell side. Monel alloy assures ductility at the -90°F operating temperatures. Unit built by Richard M. Armstrong Company.

Surest way to handle concentrated HF is in protective Monel alloy

Today, anhydrous HF is used in enormous quantities.

Yet handling of this highly reactive chemical is not likely to become routine. Various protective procedures are called for. One . . . the selection of materials for equipment in contact with HF . . . is particularly important.

For equipment exposed to concentrated HF, producers and users usually rely on Monel* nickel-copper alloy. Monel alloy shows a remarkable . . . and highly predictable . . . resistance to corrosive attack by HF.

This holds even when trace moisture or organic contaminants are present. Holds even when temperatures drop to sub-zero or rise to high levels. Take the examples above. One is 280°F hot. The other is –90°F cold.

In the first instance, Monel alloy provides the needed corrosion resistance at high temperature and meets, as well, pressure vessel requirements. In the second instance, Monel alloy not only solves the corrosion problem but also provides ductility greater than steel at this low temperature.

Are you designing equipment that may be exposed to HF?

If you are, you can obtain a wealth of HF corrosion prevention data from Inco. Design help and fabrication suggestions, too. Just contact Inco's Development and Research Division and:

Remember, when you buy

INCO NICKEL . . . you also get

INCO + SERVICES

Whenever you are looking for answers to your metal problems, all the information and help we can give you are yours for the asking. For instance . . .

- + Corrosion Service
- + High Temperature Service
- + Fabrication Help
- + Foundry Service
- + Field Information Centers
- + Convenient Sales & Service
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*Registered trademark

The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.

MONEL . . .

INCO NICKEL ALLOYS

1947-1957
A DECADE
OF PROGRESS

A DECADE
OF PROMISE
1957-1967

NUCLEONICS-10th Anniversary

Dedication

NUCLEONICS and the United States Atomic Energy Commission both complete their first decades in this calendar year. It has been a period marked by extraordinary growth. A few years earlier—say fifteen years ago—one could hardly have imagined a field or an audience for such a publication. Fermi's demonstration of the controlled chain reaction was still in the future. Even ten years ago the only reactors were the plutonium producers at Hanford and the experimental piles at Oak Ridge and the Argonne Laboratories. It took both courage and imagination to launch a magazine in 1947 dealing with a subject so recondite and a readership so limited.

Even as recently as the winter of 1952–53 the Congress was noting that there was "no major project whose purpose is to achieve a reactor directly advancing industrial power." But less than four and a half years later the number of such reactors exceeds a score, of which two and perhaps three will be operating by the time this anniversary issue is printed, with a total of five or six in operation before the present calendar year ends.

The progress in reactors has been matched by the developments in instrumentation and the use of radioisotopes in industry, agriculture, medicine and, of course, in fundamental research. In the latter field, especially, the ten years have witnessed the discovery of new transuranic elements and the identification of a number of subatomic particles of very great interest, as well as the identification of the existence of "antimatter." These developments, along with many more than can be mentioned here, have no immediate application but it would be an impetuous man indeed who would rate them as of no "practical value" in the face of recent scientific history.

During these ten years, NUCLEONICS has grown along with the expansion of the art and the industry. Closely following the affairs of the Commission, it has seemed to us at times critical, at other times encouraging—calling the plays as they appeared to the editors. There is no doubt in my mind that a very great service has been rendered to the new atomic energy industry by NUCLEONICS and—as in the matter of the survey conducted some months ago by NUCLEONICS which established the fact of the primacy of U. S. development of the peaceful atom—a considerable service to the Atomic Energy Commission as well.

The next decade should witness enormous expansion, both horizontally in the further growth of atomic applications and even more desirably in the continued discovery of fundamental natural laws. It is a safe prediction that many discoveries will be made and some of them will be great ones.

NUCLEONICS is in a wonderful field. The developments are continuous and to an extent that never existed before the lid came off, as far as secrecy is concerned, save in the military field and the functions and devices which border or parallel it. The challenge ought to keep people in this business young.

Lewis L. Strauss

Lewis L. Strauss
Chairman, United States Atomic Energy Commission

Ten years of NUCLEONICS tell . . .

The Story of a Magazine and an Industry

By **JEROME D. LUNTZ**, Editor, NUCLEONICS

AUGUST 6, 1945, is the date that has gone down in history as the one on which the might of the atom burst forth upon the public consciousness, the date the first atomic bomb was dropped on Hiroshima. August 7, 1945, is the date that started the atomic energy history of the McGraw-Hill Publishing Co., Inc.

For it was on that day, one day after the bomb was dropped, that a vice president of McGraw-Hill issued a memorandum to all publishers and chief editors in the company that laid the groundwork for extensive coverage of atomic energy in those early years and for the birth of NUCLEONICS one year later.

This came at a time when there were only vague dreams about what atomic energy might mean to the world, and even vaguer notions about the quantity and quality of information that might be available for public consumption. But, with the rosy optimism about the prospects for the growth of a dynamic, new industry, the question of whether a journal should be started to serve the communication needs of the embryo field was easy for McGraw-Hill to answer.

And so NUCLEONICS was started in mimeographed form in 1946 and as a more finished—but still experimental—venture in September, 1947, which became Vol. 1, No. 1.

"Nucleonics," as the name for the field, originated in a report, only recently declassified, prepared during the days of the Manhattan Project by a seven-man committee of distinguished scientists. On November 18, 1944, the committee (chaired by Zay Jeffries and including Enrico Fermi) submitted a 38-page secret "Prospectus on Nucleonics" to Arthur H. Compton, then director of the Metallurgical Project.

They said that the purpose of the prospectus was "to help in the formulation of sound national postwar policies appropriate to the size and importance of this field from the military, scientific and industrial standpoints." And in their introduction they defined the field:

" . . . the center or core of every atom is an exceedingly small but relatively heavy positively charged group of particles called its nucleus. In this prospectus, we are going to present some thoughts on the potentialities of that expanding field of science and industry which deals with atomic nuclei.

"We propose to use the word 'nucleonics' as a name for this field. Reflecting the modern trend toward close correlation between science and industry, and following the lead of 'electronics,' we propose that the word 'nucleonics' shall refer to both science and industry in the nuclear field."

Two years later, Jeffries suggested to McGraw-Hill that the company use the term as the name for a companion magazine to its *Electronics*.

The history of the magazine has closely paralleled the history of the field. When the Manhattan Project facilities and program were turned over to the Atomic Energy Commission in 1947 virtually nothing except basic scientific matters were declassifiable.

Thus, the avid curiosity of the "outsiders" of that day could only be satisfied with what was in unlimited unclassified supply—the basics of nuclear physics, the workings of particle accelerators, conjecture on the unlimited horizons of uses of radioisotopes, and the even more unrestrained dreams of how nuclear power was going to have more impact than the industrial revolution.

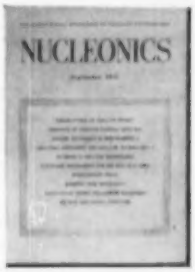
And so the first issue of NUCLEONICS led off with an article on "Foundations of Nuclear Physics" by E. U. Condon, then director of the National Bureau of Standards. This same number had two articles on radiation instrumentation, the first of a series on isotope techniques in biochemistry, the first of a series on quantum mechanics, the story of Oak Ridge's Clinch College of Nuclear Knowledge (and its now well-known students) and related educational activities, a complete copy of AEC's second isotope price list, and an extensive list of MDDC's (documents declassified from Manhattan District files).

Printed in a small, 5¼ in. × 7¾ in. format, this then was the beginning of NUCLEONICS.

To emphasize the scientific nature of the magazine and to appeal to the predominantly scientific readership, a domestic and foreign editorial board of high stature was established, with the foreign representatives including such people as Sir John Cockcroft and Frederic Joliot-Curie.

Early recognition of nucleonics as an international discipline led not only to extensive reporting of foreign activities in our pages but also to publication of articles by authors from 13 different countries: Canada, England, France, Norway, Sweden, India, Italy, Belgium, Netherlands, Czechoslovakia, Germany, Australia and Hawaii.

What follows is the story of a magazine and an industry. It is not intended to be the complete story of either. Rather it is only to show how each has grown hand in hand.



1947

This year is probably best characterized by the headlines of some of our news stories of that time: "Carnegie Tech Builds Cyclotron," "New Particles Discovered," "Radiation Chemistry Symposium Held," "University Builds Cyclotron Shield."

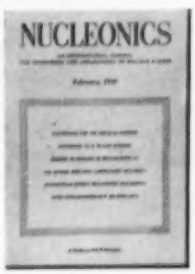
One area that NUCLEONICS has always reported very heavily is nuclear instrumentation, with increasing emphasis being placed on scintillation counters as they became more important. Interestingly, in our first issue, one of our authors said:

"If a screen coated with a fluorescent material, such as ZnS, is exposed to alpha rays, a tiny flash of light can be seen each time an alpha particle strikes the screen . . . Much of the early research in nuclear physics was conducted using this simple method of detection. . . . Recently, this method has been improved by the use of photomultiplier tubes and 'counting circuits.'"

Several months later, we reported the historically important first work done with naphathalene phosphors, which considerably improved scintillation counters.

NUCLEONICS was on its way to establishing itself as the most important publication medium for such work for quite some years—up to the recent publication of full reports of the biennial symposia on scintillation counters.

In that first year, with essentially nothing declassified on the subject, we touched on nuclear reactors rather lightly, publishing only one article, "Nuclear Principles of Nuclear Reactors," by Clark Goodman. On the other hand, we covered radioisotopes rather substantially, reporting on uses in metallurgy, friction studies, biochemistry and medicine. We carried important articles on two specific isotopes: C^{14} and Na^{24}.



1948

In April of this year, NUCLEONICS reported "first laboratory-created mesons produced with 4,000-ton cyclotron at University of California." AEC later called this

"the most important advance in nuclear science since the discovery of fission . . . "

A dual milestone for NUCLEONICS that year was the publication in May of the 106-page "1947 Summary of Nuclear Data" prepared by the Nuclear Data Committee of the then Clinton National Laboratory at Oak Ridge.

This was the first "bonus" report put out by NUCLEONICS, and in it, the publishers modestly announced, "The appearance of display advertising in (this issue) marks the beginning of the acceptance of such advertising in NUCLEONICS." This was the first evidence of the beginnings of a commercial industry.

Two articles of particular interest in 1948 were one on a "radioactive-electric converter" by two Detroit Edison men and an historic one on the use of radioactive dyes for brain-tumor detection.

In the first one, the authors said, "In connection with the utilization of atomic power for production, the question of direct conversion of atomic energy into electric energy is of special interest. If part of the fission fragments should be released as high-velocity charged particles predominantly of one sign, then these particles could be directed against a suitably arranged electrode which would assume a high potential."

Of course, direct production of electricity for power purposes is still far from reality today.

On the other hand, in connection with the brain-tumor article, radioisotopes have become quite important in this work, although not the dye method.

1949

Two rather straightforward news stories in the February issue of NUCLEONICS and the report of a speech in the March issue modestly heralded important developments in the reactor field that were to come in later years.

Here's how what was later to become the *Nautilus* was noted then:

"Construction of a nuclear reactor to be used in the propulsion of ships is to be undertaken by the Westinghouse Electric Corp. . . . A. Tammaro, manager of AEC's operations in Chicago, announced that work under the contract will be carried on in cooperation with Argonne National Laboratory . . . The objective of the developmental project is to meet requirements provided by the Navy Dept. Bureau of Ships for the propulsion of naval vessels." And now the Navy plans 75–100 reactors in the next eight years!

The second news story was entitled, "Hafstad Appointed (First) Head of AEC Reactor Division." At about the same time, AEC's scientist-commissioner, Robert Bacher, delivered a speech in which he announced this country's first reactor program (see p. 86), comprising four reactors, one of which was the Navy reactor.

But, of course, there was still little information available on reactors as such. However, in May, 1949, NUCLEONICS published the first of its frequently-referred-to series of papers on the theory of neutron diffusion by Robert Marshak, Harvey Brooks and Henry Hurwitz.

The establishment of NUCLEONICS' place in the literature can, on one basis, said to have come later that year in connection with the publication of the article, "Place in Periodic System and Electronic Structure of the Heaviest Elements" by Glenn T. Seaborg. Prior to that time, NUCLEONICS had not, for one reason or another, been abstracted by *Chemical Abstracts*, the principal abstract journal. Before Seaborg submitted his paper, arrangements had to be made—and were made—for NUCLEONICS to be abstracted regularly.

And 1949 was the first year in which NUCLEONICS published a "Buyers' Guide" listing of nuclear equipment manufacturers. That year, it ran two pages. In 1957, it will run at least the 85 pages it was in 1956.

1950

This was a year of considerable progress, administratively and technically. On the former front, the front cover story of the December issue reported AEC's action in approving the trail-blazing proposal of North Carolina State College to build the first non-AEC reactor in the U. S., a 10-kw water boiler. The initiative of the Raleigh school served to stimulate a number of other universities to follow their lead.

Another "administrative" development that was to have major repercussions indeed was the proposal that C. A. Thomas, then executive vice president of Monsanto Chemical Co., made in a college commencement address—that the government permit industry to build dual-purpose power reactors. The money the government would pay for Pu produced would go to offset the cost of the power that might be used to produce elemental phosphorus.

On the technical side, NUCLEONICS reported a number of interesting developments, particularly in radioisotope usage. As part of its then heavy coverage of medical applications, NUCLEONICS published the first of many papers on the very important work being done on treating malignancies with radiogold. Incidental to the main subject, the authors of this first article made this prediction:

"In all likelihood, only those isotopes which can be made by the chain-reacting uranium pile will have a large part in control of cancer in the future, the cyclotron furnishing an adjunct source of materials for specialized cases."

This has certainly been shown to be true.

Other very interesting applications of radioisotopes were reported in articles on the fields of entomology, micro-

biology, chemical reactions and pharmaceutical studies. The likening of the significance of the radioisotope to that of the microscope was beginning to be borne out. Interestingly, industry had not yet begun to appreciate the usefulness of this new tool.

Best evidence of the growing pains of a not-yet-really-fully-born industry was the issuance in 1950, under the aegis of the National Research Council, of a rather extensive and authoritative nuclear energy glossary. Over a number of months, NUCLEONICS published selections from this. A final version has only just been issued by the American Standards Association as the first completed standard in the nuclear field.

1951

In January, 1951, NUCLEONICS reported the details of the first significant declassification of reactor information, important but modest in scope:

"Nuclear properties of uranium of importance in the design and operation of recently declassified low-power research reactors have been released by the atomic energy authorities of the U. S., the U. K. and Canada. All of the data released pertains to uranium and reactors in which it is used. Similar data on other fissionable materials will remain classified, as will almost all values of neutron cross sections for fissionable materials at energies other than thermal."

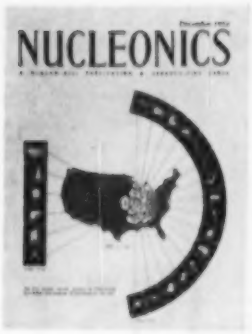
It was a number of years before this other information was released. However, the declassification did permit NUCLEONICS to publish its first full description of a reactor—ironically, a British pile, GLEEP, at Harwell.

Further evidence of the growing international interest in atomic energy—and the fact that this business was no one country's secret—was the feature article NUCLEONICS published in November, 1951, on the 100-kw heavy-water reactor that the Norwegians had just put into operation.

Large radiation sources came in for considerable attention in 1951. The Stanford Research Institute completed a study for AEC on the use of gross fission products from production plant wastes and concluded that "a market of the order of hundreds of thousands, or even a few million, curies per year seems likely if the price is a dollar or so per curie. If the price is $50–100 per curie, the market will probably be in the tens of thousands of curies per year."

As of now, the economics and technical problems of handling and using gross fission products have not made them particularly attractive.

However, in parallel with the Stanford study, Brookhaven carried out work on producing and using kilocurie Co^{60} sources to simulate large fission-product sources. This work, which Bernard Manowitz first reported in NUCLEONICS in August, 1951, turned out quite well and led many to research with and later acquire Co^{60}.



1952

This was a key year in many ways for the nucleonics industry and for NUCLEONICS. It was, in fact, a turning point for the magazine. For this was when, having sensed the growth of the field, McGraw-Hill took NUCLEONICS out of its swaddling clothes and dressed it up in full-size garments—our present $8\frac{1}{4} \times 11\frac{1}{4}$ in. format.

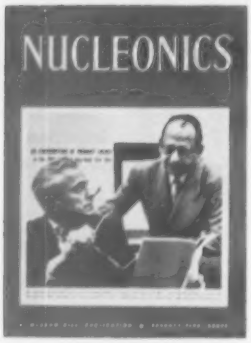
Nuclear reactors became a thing of importance—to us in our coverage and to the industry, in general. Attesting to the surging activity in reactor technology was our publication in March of what has since become the grandaddy and forerunner of many nuclear reactor catalogs. H. S. Isbin, who compiled that catalog (and the one for the UN at Geneva in 1955) said then that "the development of nuclear reactors has expanded to the point where now more than 25 reactors have been built and operated. Currently, there are more than ten reactors reported to be in advanced stages of design and/or construction, with probably at least an additional half dozen in initial planning stages."

Compare this with AEC's statement in its latest (22nd) semiannual report: As of June 30, 1957, there were 267 reactors built, building or planned in the U. S.

Eleven days short of the new year, 1952, the Experimental Breeder Reactor went into operation in Idaho and produced the world's first nuclear-electric power—100 kw of it. NUCLEONICS featured it on the front cover of the February, 1952, issue. And in September carried an article by W. H. Zinn, then director of Argonne and responsible for EBR, with the first details of the facility. In this article, Zinn said that unless AEC built dual-purpose reactors on government reservations "a much longer time for expensive development and experience (would be necessary and there would be the) risk of seeing central-station electrical power developed in countries where the lack of conventional energy resources makes the need much greater."

In November, 1952, Alvin M. Weinberg, now director of Oak Ridge National Laboratory, in a guest editorial, pointed out the attractiveness of small (5,000 kw_e), cheap nuclear power packages for use in remote localities and proposed that NUCLEONICS carry out a market study for 3¢/kwh electricity. Such a study was conducted and showed no domestic market but a rather interesting foreign potential, plus, of course, the military market.

Up to this time, the only reactor contemplated for non-AEC sites was the Raleigh water boiler. In November, W. M. Breazeale presented a first report on what has now become one of the most popular of research reactors—the "swimming pool." He pointed out that this type "is relatively so inexpensive to construct and simple to operate that its installation is hardly a major project."



1953

This was the year that the groundwork was laid for bringing industry into the picture on a fullfledged basis—on its own and as a partner of government. The extent to which legislative activity and environment could influence a technology became apparent in the exploratory hearings conducted by the Joint Committee on Atomic Energy on possible revisions in the basic atomic energy law.

In a 16-page cover story, NUCLEONICS reported that "all (witnesses) are in essential agreement that there is an urgency for this country to develop a strong civilian nuclear power development program. The urgency for this comes not so much from the need for a new, low-cost source of energy as from the vital necessity for this country to maintain international pre-eminence in reactor technology."

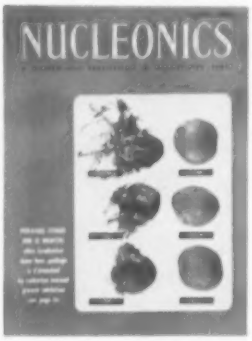
The stage was now set for Thomas E. Murray, then an AEC commissioner, to announce in what NUCLEONICS called "one of the most forceful talks made by a commissioner" that the development of economic nuclear power was an urgent national goal. In the same speech, Murray announced that AEC had decided to build the PWR. At the time, many fears were expressed that because the reactor would use enriched uranium it might not help us in the international race. NUCLEONICS said editorially that "if instead of merely trying to get the PWR built for the sake of having an operating civilian power reactor . . . the economics of the system (are) uppermost in its planning, this country may approach its goal in the world nuclear power race—practical nuclear power rather than just nuclear power at any cost." Unfortunately, it now appears that the cost of power from PWR will be close to 60 mills/kwh.

With the completion of nuclear power feasibility studies, this year also saw industry move further into the limelight. Probably the most useful result of the studies was the thorough "paper" indoctrination that the groups got. The chemical companies involved—Monsanto and Dow—learned that they really weren't interested in nuclear power, except possibly as customers. Only two of the utilities in the original groups—Detroit Edison and Commonwealth Edison—are importantly involved today, the former in its fast breeder project at Monroe and the latter in a boiling water plant at Dresden.

The arguments still raged on the merits of dual- vs single-purpose power reactors, and NUCLEONICS added fuel to the fire with a pair of articles. One said that dual systems "should provide as much push toward the more advanced power breeders as anything that can be done today." But the other pointed out that "the construction now of a dual-purpose plant would not eliminate the need for a single-purpose plant. Only a single-purpose plant can produce useful data on nuclear power cost." It's interesting that the British, at their Calder Hall dual-purpose plant, are gaining very useful engineering and cost experience.

Breeding, the reactor dream of that era—and maybe not of today—proved possible. It was on June 4 that AEC announced the first experimental verification of the breeding principle.

In 1953, NUCLEONICS began publication of one of its most important and extensive series of articles—on radiation sterilization. When it was concluded in 1955, we found that $2-million was being spent annually on research at that time, and it appeared that within a short time it might be commercially feasible to sterilize three products: drugs, small surgical products, and potatoes. Other food items would take 5–10 years more of study.



1954

Developments in the field—progress plus declassification—made it possible for NUCLEONICS in this year to start establishing itself as a principal source of information on reactor technology. The July issue contained two very important reports. One was the collection of seven articles on Brookhaven's liquid metal fuel reactor concept. This work paved the way for the advanced work now being done on the LMFRE.

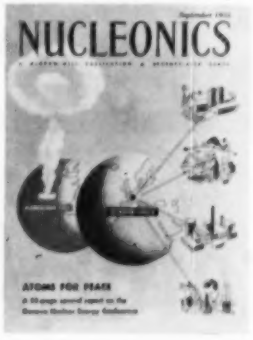
The other important July article was Samuel Untermyer's report on the first work—at Argonne—on boiling reactors. He foresaw that when it's possible to have higher reactor temperatures and pressures and "if steam could be generated within the reactor at the critical temperature, at 3,305 psi, a thermal efficiency of about 40% could be obtained" with boiling reactors. The first version of the Experimental Boiling Water Reactor at Argonne, which went into operation in 1957, has an efficiency of 20–25%. The expected efficiency of the first central-station boiling-water reactor plant, at Dresden, is 25–30%.

Another historic development in the reactor field in 1954 was the first issuance of fixed-price bid invitations to build a reactor—the Army Package Power Reactor. NUCLEONICS editorially pleaded with the 33 prospective bidders to "make it an honest bid" because of the demoralizing effect that underbidding might have on the industry. The initial contract awarded to Alco Products, Inc., was for $2.1-million. This was later upped to $2.4-million. The latest cost estimate is $3.5-million.

With reactor projects mushrooming in 1954, AEC coordinated its plans and came up with a five-year program costing $242-million. It included two versions of the homogeneous reactor, EBR-2, EBWR, SRE and PWR. Three of these have operated with three yet to go into operation.

In one of the first such projections, James Lane evaluated the "growth potential of the U. S. nuclear power industry" in the June NUCLEONICS, based in part on AEC's five-year plan. He pointed to prospects for a $400-million annual nuclear equipment business by 1967, and over $3-billion by 2000. See trend curve on p. 108 for current thinking.

Not to be overlooked, of course, in any report on the year 1954—because it made everything that follows possible—is the new atomic energy law. It permitted full industrial development of nuclear power and full international cooperation.



1955

This year will go down in history for two things: the Geneva "atoms for peace" conference, and the announcements of work being done on controlled fusion.

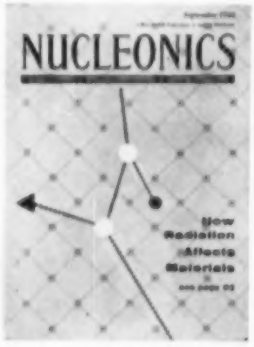
NUCLEONICS devoted its entire September issue to the conference and reported from Geneva "that the meeting was an unparalleled success. In fact, there may never be another technical meeting with such a profound effect on technological progress and international relations at the same time." This was the occasion when the USSR revealed for the first time a great deal of what it had been doing in the atomic energy field. And this was the occasion for which the U. S. outdid itself on declassifying information and in presenting a very bold program.

There is little doubt that the Geneva conference has had major impact—on big countries and little countries. As NUCLEONICS reported in a conference followup report, based on interviews in Geneva, many of the small countries really had their eyes opened on the realities of nuclear power, how little had been accomplished and the many unknowns in the field. But many of these countries used the Geneva as the stepping-off point for their present-day programs.

The large countries were really able to take stock on how they stacked up against their competitors. And it has been interesting to see how frequently today's technical literature refers back to information released for the first time at Geneva.

Of course, the most startling revelations to be made at the conference were in the thermonuclear field. The conference president, Homi J. Bhabha of India, surprised the world by raising the subject at the opening session. In quick succession, the U. S., the U. K. and the USSR owned up to the mere fact of having controlled fusion efforts.

NUCLEONICS has long had an interest in following the subject as closely as the tight classification permits. In fact, it was in June, 1954, that the magazine first reported AEC's work in this area. Then, about simultaneous with the Geneva conference, J. G. Beckerley, a former AEC director of classification, in a very controversial guest editorial, pleaded the cause of reduced secrecy, as he had many times previously in the pages of NUCLEONICS. This time, however, his subject was fusion secrecy. Although certain theoretical information has since been released, virtually no practical data has come out. In fact, one of the most advanced statements at the time was the 1956 speech at Harwell by the Russian, Igor Kurchatov, published in the June, 1956, NUCLEONICS.



1956

The story of 1956, the last year of the first decade of the peaceful atom, is the story of the burgeoning international atomic power race. It appeared then—and it still does at this writing—that international political considerations might well move the U. S. nuclear power program in unwarranted directions.

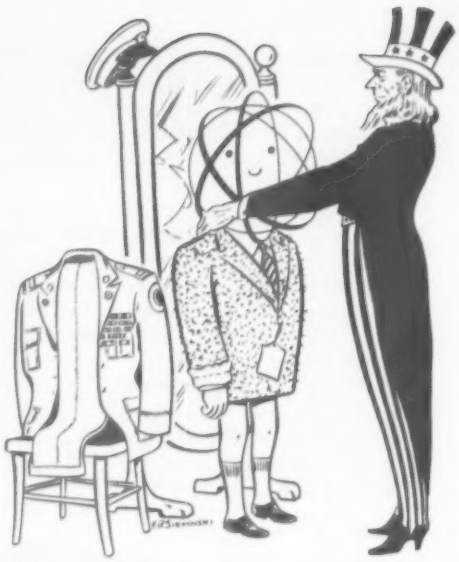
The two main questions raised were: Who is building the most nuclear kilowatts—the U. S., the U. K. or the USSR? And whose plant is better—the U. K.'s Calder Hall or the U. S.'s Shippingport?

In an August, 1956, editorial, "52 Mills vs 7 Mills," NUCLEONICS pointed out how meaningless such cost data is today and criticized officials for bandying about numbers on the cost of Shippingport power because of the confusing picture presented to the world.

In an October editorial, "October 17, 1956," NUCLEONICS saluted the British on a day of pride not only for them "but for all the world"—Calder Hall was on the line.

And then, in a very unusual two-day symposium in London that November, the U. K. told almost all about their plant, with NUCLEONICS reporting Sir Christopher Hinton's boast that Calder "is giving us the initial lead in the use of nuclear power and we shall be able to retain that advantage for at least a decade by improvements in this type of reactor."

Meanwhile, however, NUCLEONICS has been reporting an export race that shows that the U. S. has sold 6 power reactors and 25 research reactors, with 0 and 3 respectively, sold by the British.



MR. ATOM — Out of Uniform, 1947 . . .

Political History of the Peaceful Atom

By CORBIN ALLARDICE and EDWARD R. TRAPNELL

TEN YEARS is not much perspective from which to write a useful commentary on the national atomic energy effort. It is not our purpose to review or chronicle the events that seem to mark the mileage points of progress toward realization of the promise of atomic energy. Rather, we want to present the ebb and flow of a few important issues and the changing patterns left upon the national atomic energy program in a way that will stimulate continuing critical examination of that program and its direction.

Initial Direction

The first decade set the direction, if it didn't plot the course, of national development of atomic energy. Despite the responses to changes in domestic and international political winds, the general objectives have been clear: To strengthen national defense for the protection of the free world and to realize the benefits of atomic energy for the improvement of man's lot everywhere.

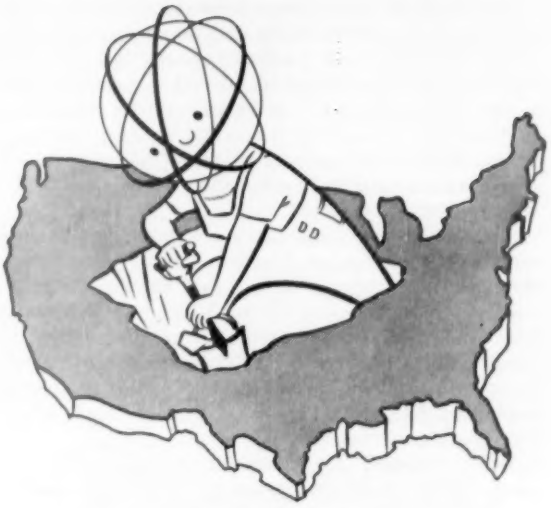
These were the objectives of the McMahon Act, which carried such hopes for the realization of the benign promise of the atom, but which, because of Soviet intransigeance, had to serve primarily the military objective. Indeed, it made progress toward the peacetime objectives practically impossible on the international side and quite cumbersome on the domestic side.

First law. The first atomic energy statute, known officially as the Atomic Energy Act of 1946, reflected not so much the philosophy of the majority in the Congress at the time as the straightforward acknowledgment by politicians that the American people appeared to want—with as much confusion as determination—an unequivocal and unquestioned control and domination by the federal government of this new field of demonstrated destructive potential, of obvious, but little understood, danger to human life, and of immense promise for good mankind.

If only a few Americans could embrace the underlying philosophy of the 1946 Act, most could justify it on the grounds that the times called for bold action much as opportunity beckoned to Jefferson to make the Louisiana Purchase without saying 'boo' to anybody, or, in the same way that economic conditions impelled Jackson to establish a federal treasury, or that depression furnished the impetus to the New Deal's exercise or extension of federal powers in a manner possibly unprecedented but obviously not just temporary.

It has been said that although the McMahon Act took Mr. Atom out of uniform, it put him in a strait jacket. The Atomic Energy Act of 1954, otherwise known as the Cole-Hickenlooper Act, loosens the arm-straps of the straight jacket, but the entanglements of some of the unbuckled straps continue to restrain the victim.

The Cole-Hickenlooper Act provides the basis for the



. . . at Work in the U. S. A. . . .

. . . Citizen of the World, 1957

establishment of a new industry and removes some of the barriers to international cooperation, but in the three years since its enactment, progress toward the first of these goals has been slow, painstaking, and not entirely satisfactory to anyone. While the federal monopoly was indeed ended in 1954, residual federalism in the administration of programs designed to further the objectives of the Act retards the solution to problems facing a new industry low in profits and high in risk.

Military needs. The evidence that civil vs. military control of the atom was more of a diversion than an issue began to impress the first five commissioners very early in their terms. The evidence: The war-built complex of plants and laboratories and storage facilities was not in shape to support and sustain the military preparedness effort that was becoming obviously necessary, even before the real nature of postwar Sovietism became clear.

The first three years of the civilian management of the atom was a period of consolidation, revamping and what the oil refinery people call "turn around" to ready the vast production system for the efficient manufacture of munitions on a large scale.

The irony of the whole thing was that the "civilian control" managers of the atom had to concentrate on the military requirements. They were able to concentrate on national defense aspects of the program because, interestingly, during the period of September 1945 to December 1946 the military managers of the atom had done so much planning for some of the peacetime needs.

But in the waning hours of the Manhattan Project, the military side of the program proceeded at a snail's pace as far as long-range planning was concerned because the country was debating civilian vs. military control and there was so strong a hope for a workable system of international control of atomic weapons. General Groves kept his production plants going, kept up the flow of raw materials as best he could and encouraged development work on weapons at Los Alamos but could do little more.

Peaceful uses. A great deal of long-range planning was done, however, on the nonmilitary side. Even before the war was over, planning had started on the conversion to peacetime status of the extensive research and development facilities. The changeover presented no problem because of the policy of using existing organizations—industrial and educational—to manage segments of the far-flung program. This practice was continued by AEC.

The University of California still runs Los Alamos, the University of Chicago still runs Argonne. General Electric took over Hanford in the late summer of 1946, absorbing most of the DuPont-trained team.

Brookhaven National Laboratory was still in the con-

Corbin Allardice (right)

and

Edward R. Trapnell

Respectively, atomic energy advisor to the World Bank and atomic energy specialist at Bozell and Jacobs, advertising and public relations firm.

ceptual stage as far as its actual management was concerned, but the idea for management by Associated Universities was well formed when the Commission took over. Work was already underway at the site. Knolls Atomic Power Laboratory, to be operated by GE at Schenectady, was on the way.

The distribution of radioisotopes, the use of which General Groves forecast would more than repay the American people for their entire investment in the atom, had started in the spring of 1946 and was a going program by the end of that year. Argonne and Oak Ridge, the latter then known as Clinton Laboratories, were already conducting training programs in the use of isotopes.

Rehabilitate, Reorganize, Recruit

In its own resume of the first decade, the Atomic Energy Commission said the period 1947–49 was one of "rehabilitation, reorganization and recruitment." The words cover a lot. The period wasn't all peaceful, either between the Commission and the Congress or the Commission and the military establishment.

First AEC Chairman Lilienthal, like present Chairman Strauss, had the ability to ruffle the feathers of some politicians. He was twice put in jeopardy by committees of Congress, once on his confirmation and once in the famous "incredible mismanagement" hearing into AEC's ideas of "rehabilitation, reorganization and recruitment." And in between, one of the members of the Commission complained to President Truman about what he termed "General Groves' interference" with the programs of the AEC. The President cut the complainant short with the remark that he knew all about it. An ex-Manhattan District employee of the Commission explained that Mr. Truman had kept a check on things atomic ever since he had been barred from admission to Oak Ridge as wartime chairman of a Senate investigating committee.

More was done in those first three years than just rehabilitation, reorganization and recruitment. A lot of real building, some sound planning and valuable research were done, as was some pretty good thinking about the job of developing fission reactors for power.

Reactor development. By the end of 1949, the Commission could describe its reactor development program as consisting of four main projects: a materials testing reactor, a ship propulsion reactor, an experimental breeder reactor, and an intermediate power breeder reactor.

Behind this first publicly identified reactor development program was more than two years of scientific and administrative soul searching. The first reactor development program was formulated by W. H. Zinn, then director of Argonne, in a Washington hotel over a weekend in February 1947, at the request of the AEC's first general manager, Carroll L. Wilson. Out of his paper came the MTR (once called the reactor development reactor), the experimental breeder, the pressurized-water system for STR, and specific recommendations for work on sodium-cooled systems and heavy-water-moderated nuclear reactor systems.

The priority subsequently given the MTR by the Commission related to the decision to hold up on the so-called Daniels Pile, a gas-cooled system, on grounds that not enough was known about the materials needed for the job.

L. R. Hafstad, then director of reactor development for the Commission, defended the 1949 four-project program, saying the AEC scientific advisers agreed "that four, and only four, experimental reactors should be the initial goals of the Nation's program," and that "only by strong support behind each one, both in men and in money, can there be any likelihood of success," and that "diffusion of effort over too many reactors would almost certainly lead to disappointment and failure."

The limited program of four reactors—limited because more would have meant dilution of effort, apparently—didn't include the gas-cooled, natural-uranium power reactor project launched by the Manhattan District at Oak Ridge. Hafstad's prophecy of disappointment doesn't still hold, since the U. S. program continues to grow, with the Joint Committee itself adding projects to a program defended by Chairman Strauss on grounds of its diversity and variety.

Navy program. Significant for our reactor development effort was the emergence in AEC's early years of support for a Navy nuclear power program. One of the arguments against the Daniels Pile was that it couldn't possibly even approach economic practicability. The question was asked: "Why not use the military crutch?" For the Navy, nuclear power offered advantages worth any price, as Commissioner Sumner Pike made clear in explaining the Commission's decision to concentrate on development of a submarine power plant.

This concentration on naval requirements—for which the nation is indebted to the late Rear Admiral W. S. (Deke) Parsons, who took up the argument long before it became fashionable—has paid well. For naval purposes, the *Nautilus*-type pressurized-water system, pushed to its ultimate development by Rear Admiral H. G. Rickover, is a major factor in the establishment of a nuclear Navy.

The extension of pressurized-water technology to meet manifold naval propulsion requirements is now well under way, despite the Bureau of the Budget denial in 1953 of a Navy request for funds to build a heavy carrier propulsion system. By a strange twist, this turn-down by the Bureau of the Budget and an intercession by the Joint Committee led directly to setting up the Shippingport project, which, according to Admiral Rickover's cost estimates, has slight possibility of economic practicality. The know-how learned at Shippingport, however, should be profitably applicable to the systems designed for Consolidated Edison, Yankee Atomic, and to the more advanced water-cooled systems stemming from Argonne's boiling experiments.

The impact of the Navy program on the commercial nuclear power business should not be minimized. It has enabled manufacturers to acquire necessary new skills and competence while serving the national defense. But it has also directed work to the achievement of a technical certainty without regard to cost. Economic power requires a balance of the two.

The needs of the Navy were further reflected in the change-over of the intermediate power breeder project at Schenectady to a naval propulsion project, again avoiding the stringencies of power economics.

At least one prophecy made in the early years seems to be standing up pretty well. In 1947, the Commissioners asked the General Advisory Committee to prepare a state-

ment on the subject of atomic power. The first version was returned to the GAC on grounds that it was so short and succinct that the AEC's public information office couldn't possibly answer all the questions it would provoke. The GAC dutifully rewrote the statement, which ended with this paragraph:

"Even on the assumption of a most favorable and rapid technical development along these lines, a word of caution is needed as to the time scale. We do not see how it would be possible under the most favorable circumstances to have any considerable portion of the present power supply of the world replaced by nuclear fuel before the expiration of 20 years."

Expansion of Effort

That first phase of "rehabilitation, reorganization and recruitment" in the nation's atomic energy program was roughly jolted into a new phase by the Russian explosion of an atomic bomb late in the summer of 1949. It meant that intensive effort to harness the energy of fission for useful work again would not hold its place of prominence in the Commission's deliberations, toward which it had been slowly climbing in the face of military preoccupation of the civilians appointed to manage the atom.

Near the close of this early period was an event which didn't appear nearly so significant at the time as it does now—the appointment by the Joint Committee on Atomic Energy of a subcommittee on reactor development and a report in 1949 which said the subcommittee (under Rep. Carl T. Durham, its first chairman) "believes that reactor development should proceed with all possible speed, and disappointment therefore follows from reflection that in 2½ years the Commission has not broken ground on a single new-type high-power reactor."

The significance stems from the fact that since 1949, the Joint Committee has been the most active stimulator of the AEC power reactor program and the appointment of Durham's subcommittee was just the starter. About the same time the Joint Committee was girding for its own push on reactor development, the Commission created a Division of Reactor Development to bring under one manager the far-flung and then somewhat disconnected work going on in the field.

The Joint Committee, even though it commended the Commission in 1951 for "genuine gains" in the reactor program, continued to press for more progress. In 1952, the Joint Committee called for a coordinated program of power reactor development with "defined objectives." Two years—and several letters—later, the Commission submitted to the Joint Committee its five-reactor program—pressurized water, second breeder, homogeneous, sodium-graphite, and boiling water.

In defense of the Commission, it should be recalled that the 1950–53 period was the time of the great expansions for national defense reasons—Fernald, Rocky Flats, Paducah, Portsmouth, Savannah River, completely new plants at Hanford and Oak Ridge—with AEC accounting for more than 3% of all construction activity in the United States. This was also the Korean War period, and the period that saw the establishment of a continental weapons test site in Nevada, the build-up of a national reactor testing farm in Idaho, and the push for the H-bomb.

During that busy period, the Materials Testing Reactor started work, the first experimental breeder reactor proved the feasibility of breeding and first made electricity, the submarine prototype began operating, the homogeneous system was proved in principle, isotope usage and benefits soared, special hospitals were completed, cobalt-60 came into use as a substitute for radium, new elements were found, the biggest accelerator yet built was completed and ideas for even bigger machines were being studied.

It was indeed a period of progress, and, perhaps not coincidentally, it was the period of best relations between the Congress and the Commission, then headed by Chairman Gordon Dean, who served from early 1950 until mid-1953.

Study teams. The Commission sent to the Capitol in the spring of 1953, in response to a request from the Joint Committee, some proposals, without specific legislative language, for amendments to the Atomic Energy Act to speed the development of nuclear power and to permit private investment in development and facilities.

As far back as 1947, there had been studies and reports—abortive for the most part—on how industry could get into the atomic energy picture. In 1951, industry invited itself into a more meaningful role than had yet been outlined by any of the planners when Charles A. Thomas, president of Monsanto Chemical Company, proposed a scheme under which study teams of industry representatives could get a look for themselves, for their own purposes, at the equipment and data gathered behind the security wall.

The result of this proposal was that a number of study teams, drawn from groups of industries, began to educate themselves with more text material than they could find in published literature or than was normally available under AEC contracts. This was the first breach in the "need to know" wall. Up until this study program, the only "need to know" for access to classified information was when the Commission needed you to know. After passage of the 1954 Act, the Commission introduced an access-permit program, which is little more than an expansion of the "study" program and hardly a substitute for declassification, to expand the rolls of the students from private industry.

There were other important results of these studies. From one study came the imaginative and long-range-payoff power breeder, which is now the Power Reactor Development Company project at Monroe, Michigan, currently beset with intervention proceedings stemming primarily from the Commission's failure to consider the public relations hazards along with the radiation hazards in its efforts to speed the project.

The Commonwealth Edison nuclear power plant at Dresden, Illinois, is an outgrowth of studies made by a group that decided the boiling water system, then in its earliest stages at Argonne, held the greatest promise for nuclear power at a price a utility could afford.

Many of the companies now involved in reactor projects of one type or another took part in that pre-1954 evaluation of reactor systems. The very fact that so many different systems are under development with industrial sponsorship is impressive testimony in support of the Joint Committee's comment (in reporting the 1954 Act): "We do not believe that any developmental program, carried out solely under government auspices, no matter how efficient it may be, can substitute for the cost cutting

and other incentives of free and competitive enterprise."

The 1954 Act

The Joint Committee was applying precisely the concept behind the words "strengthening free competition in private enterprise," so valiantly set forth in the policy statement of the McMahon Act. The members of the Committee and its staff, who worked intermittently through the winter of 1953–54 and intensively after receiving specific language recommendations from AEC in the spring of 1954, couldn't foresee the squabble ahead for the principle to which everybody seemed to subscribe up to that time.

The revision of the Act was finally passed and, on August 31, 1954, President Eisenhower signed it into law. The new law, while not entirely satisfactory to anyone, is, in balance, a good legislative enactment. Without inflexibly establishing detailed procedures, it provides the AEC, as the responsible federal agency, with the necessary powers to control and regulate—without necessarily dominating—the national development of atomic energy.

The Act permits private development under license and regulations of all but the purely weapons portions of the field of atomic energy. It encourages both government and private initiative and frankly recognizes the need for close partnership between the two.

In essence, the approach to federal control envisaged in the Cole-Hickenlooper Act has a three-pronged root: control of information, control of materials, and control of facilities. The AEC can say what information can be freely published and what cannot. It can restrict or allow possession of special nuclear materials, and it can license the ownership and operation of nuclear facilities.

Because the operation of nuclear facilities could have serious effects on public health and safety, the AEC also has responsibility and authority to establish and enforce health and safety standards. In the field of patents, the AEC is given unique, constitutionally untested, and clearly controversial powers to enforce compulsory cross-licensing of patents important in the nuclear field.

In the never-never land of atomic energy, it is difficult to find blacks and whites. The Commission itself is proof enough. It has the obligation under the Act to *encourage* the development of atomic energy, even to the extent of providing material stimuli. But the same Commission also has to regulate the business it is supposed to encourage. The irony wasn't lost on the Joint Committee even back in 1954, which considered the possibility of separating the two functions so that the same Agency wouldn't be passing on licenses to produce materials, at prices that it would set, and of which it was the sole existing producer.

The Joint Committee was persuaded by the Commission that it was then premature to consider that problem that all admitted had to be faced some day. It now seems as though "some day" is nearer to today than tomorrow.

The problem is not so much a separation of the Commission's functions as a clarification of them. Until these functions are clarified, they can't be separated. It is no answer to suggest, as some have, that the Department of Defense take over the munitions side—manufacturing and weapons development, that National Science Foundation take over the peacetime research and development work, and that the Commission be restricted to the regulatory functions.

For one thing, the three fields overlap. For another, there aren't enough qualified people to staff three separate organizations. Furthermore, there isn't much to regulate —and there won't be very soon unless the "encouragement" is done first. Those who oversimplify this problem do so from a lack of understanding, or a lack of sympathy, with the objectives of the Act.

International activity. On the international side, the 1954 law makes possible international cooperation in the peaceful uses of atomic energy. Through the mechanism of statutorily authorized but circumscribed "agreements for cooperation," the United States is enabled to act as its sense of international responsibility and good will dictates.

It is not our purpose here to analyze the 1954 Act, with all its provisions, checks and counterchecks, its many adequacies and its few shortcomings. Internationally, it is clearly far-sighted, and the U. S. relationships with friends abroad have benefited immeasurably. It offers not only support for what is now the International Atomic Energy Agency but also, by its very passage, emboldened the Executive to push to ultimate creation that dramatic idea so forcibly presented by President Eisenhower on December 8, 1953—an idea, interestingly enough, suggested quite independently to him in a letter sent to Denver in August 1953 by Chairman Sterling Cole of the Joint Committee.

Midway during the long period of negotiations on the International Atomic Energy Agency, the whole idea of cooperative international effort to exploit the peacetime atom received a shot in the arm from the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy, a gathering of the world's scientists suggested and successfully supported by Chairman Strauss that helped demonstrably to correct the imbalance among nations in the technology of the atom.

The 1954 law is summed up by Arnold Kramish and former Commissioner E. M. Zuckert* in these words:

"The Atomic Energy Act of 1954 provides a causeway from the island of socialism occupied by atomic energy under the McMahon Act to the broad mainland of a practical degree of free competitive enterprise. The Act gives industry freedom to enter the atomic business on its own account, but not completely as a free agent."

When they wrote that industry would not be a completely free agent, Messrs. Zuckert and Kramish could have had in mind the politico-legal-administrative entanglement of access permits, authorization bills, regulations, reactor safeguard reports, compulsory patent licensing, Sec. 202 hearings, federally underwritten liability insurance, preference clauses, and all too frequent consultation with the responsible agency of government, soon to be removed 30 miles away from the seat of government to a site previously unserved by surface, rail or air transportation.

But the inefficiencies of administrations, the compromises of politics, the ironies of time, and the inconsistencies of policy are but the extravagances of a frontier —a frontier approached only ten years ago, opened only three years ago, and whose horizon lies in the stars.

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* Arnold Kramish, Eugene M. Zuckert, "Atomic Energy for Your Business" (David McKay Co., Inc., New York, 1956).

At NUCLEONICS' Request

Three Nobel Laureates Look into the Future

Harwell, England

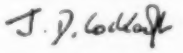
During the next decade I forsee a great development of the nuclear power program in Great Britain. Already we have planned to install 5,000—6,000 Mw of capacity by 1965, and we have seen that the capacity of an individual two-reactor power station will jump from 300 to 500 Mw between 1960 and 1962. This increase in output of individual stations is likely to proceed fast and be limited only by what the electricity networks can stand. In Britain nuclear power is likely to achieve parity with oil and coal power by 1962 and thereafter to be cheaper.

Beyond this I can foresee new types of nuclear power stations coming into commission, operating at higher temperatures and efficiencies and over-all burnups.

During this period too I foresee research and development on fusion reactions expanding and moving toward the phase where a positive power gain is in sight. I do *not* foresee economic fusion reactors for this decade.

During this period several "demonstration nuclear ships" will be sailing the oceans and by the end of the decade parity with oil propulsion may be in sight.

Forecasts of developments in pure nuclear physics are well known to be virtually impossible. We can, however, foresee new types of accelerators reaching out to the 100-Bev energy region and that many new "strange particles" will be found. I doubt whether theory will catch up with the flood of new discoveries during the next decade.



John D. Cockcroft, *director of the Atomic Energy Research Establishment at Harwell, recipient with E. T. S. Walton of 1951 physics award for pioneer work on transmutation of atomic nuclei.*

Goettingen, Germany

You have asked me, on the occasion of the tenth anniversary of NUCLEONICS, to give my opinion of the future development of my special field of work and the development of nuclear research in particular.

First, I must inform you, to my regret, that since 1945—that is, before the birth of NUCLEONICS—I have not been performing my own experimental work. After my not entirely voluntary eight months' stay, mostly in England, "at the pleasure of His Majesty," I was made president of the former Kaiser Wilhelm Institute, now the Max Planck Institute, a sort of general manager who is in charge of the forty institutions of the institute. However, I cannot pay very thorough attention to any of them, not even to those to the development of which NUCLEONICS is dedicated.

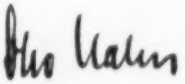
After I had demonstrated the fission of uranium and thorium with Mr. Strassmann at the end of 1938, we continued our radiochemical research and during all of the war years published our results. At the beginning of 1945 we had a table of exactly 100 fission products; the first American table, more detailed, appeared at the end of 1946.

Since then research has made great advances, and it is an unforgettable memory to have been able to be present when Glenn Seaborg discovered several atoms of element 101 in Berkeley at the end of November, 1955.

Out of artificially radioactive fission products, discovered only with the Geiger-Mueller counter, and other elements all the way up to transuranium ones have now come mass tables with which the chemist can work, just as if they were ordinary elements. I am convinced that with these the use of radioactive isotopes will be applied for peaceful purposes—medicine, agriculture, technology.

And how long will it take for the fission of uranium with its controlled chain reaction to be replaced as a source of energy by the fusion of hydrogen into helium, not, as I hope, for the production of hydrogen bombs, but for the production of energy? Then will the great problem of producing electricity be solved forever.

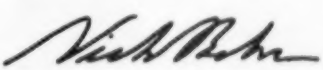
So let me wish NUCLEONICS for the next ten years a development as vigorous as it has had in the first ten years.



Otto Hahn, *president of the Max Planck Institute, recipient of 1944 award in chemistry for discovery of the fission of heavy nuclei.*

Copenhagen, Denmark

At the tenth anniversary of NUCLEONICS I want to offer my congratulations for the outstanding way in which this journal has contributed to keeping the world community of physicists and engineers abreast with the rapid development in a new field which holds out such great promises for science and technology. To those who have witnessed the development since Rutherford's discovery of the atomic nucleus in 1911, it has been a true adventure to follow the progress which step by step should so marvelously augment our knowledge of the atomic constitution of matter and entail consequences of such an immense practical importance. As regards the future, we reckon that in scientific respect, notwithstanding all surprises which may be revealed by continued research, it shall be possible to obtain an ever more harmonious synthesis of experience. From a human standpoint, it is equally clear that any increase of our knowledge means a greater responsibility, and we must trust that by growing understanding of the situation, humanity shall succeed in turning the great advance of science and technology to the benefit of all people.



Niels H. D. Bohr, *director of Copenhagen Institute for Theoretical Physics, recipient of 1922 physics award for development of atomic orbital theory.*

1947-1957
A DECADE
OF PROGRESS

A DECADE
OF PROMISE
1957-1967

A LOOK AHEAD—Although the first decade of the nucleonics industry set certain patterns, the future is far from clear. To stake out the problems and trends of the next decade, the editors of NUCLEONICS invited outstanding authorities to look into their crystal balls. Their forecasts are presented in the next 57 pages. The first is . . .

POWER REACTORS

1. the government view

By W. KENNETH DAVIS, LOUIS H. RODDIS, Jr. and CLARK GOODMAN

THE NEXT DECADE will be a most significant and critical period for the development of nuclear power in the United States. The truly unique situation with respect to the development of nuclear electric power is often misunderstood or ignored even in the broad considerations of the over-all development.

The Government through the Atomic Energy Commission has undertaken, as a matter of national policy, to develop an entire new technological industry, for which equipment, plants, and services must be entirely supplied by private industry and in which the utilization will be entirely by existing power-generating and -distributing companies.

This is true despite the fact that governmental regulation can be expected to continue, that the Government will continue to supply enriched fuel materials, and that it may supply some services such as chemical processing and waste disposal until commercial services are available. Further, although there are many compelling reasons for developing nuclear power, immediate economic necessity in the U. S. cannot be reckoned as one.

What the next decade holds in store can be discussed in terms of problems, plans, and probabilities.

Problems

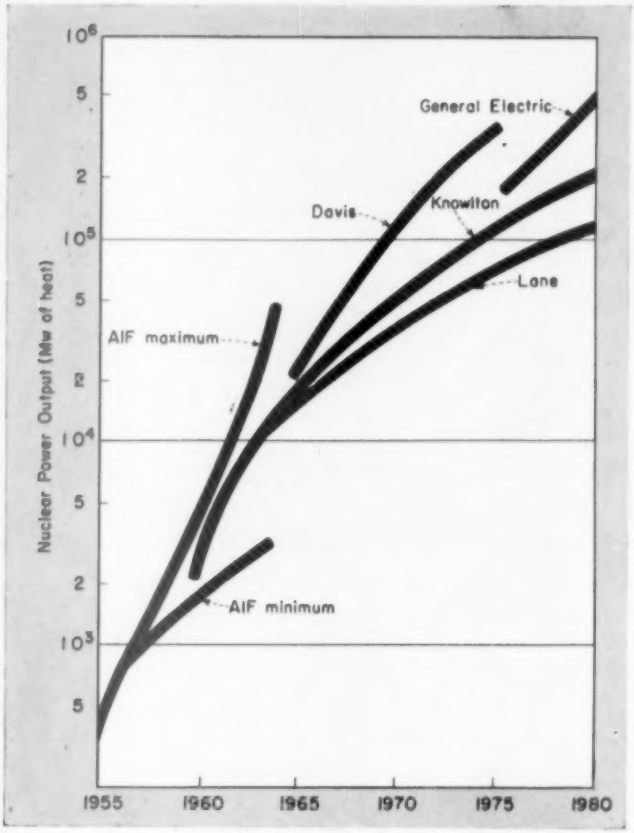
The problems that have arisen in carrying out the civilian program set forth in the Atomic Energy Act of 1954 are of three general types: public policy, technical, and economic. Their solutions will determine to a considerable extent the progress to be made in nuclear-power technology in the next ten years.

Public policy problems. Congress has debated at length but has not yet determined what should be the balance between government and private industry in developing this new source of energy. The division of responsibility between the Joint Committee on Atomic Energy and the Atomic Energy Commission has also been, and continues to be, a subject for considerable debate. The extent and nature of governmental economic assistance that should be offered to American industry in these developments is still an unsettled question. Likewise, the extent and nature of United States assistance, both economic and technical, to friendly foreign nations is still in the process of formulation. The lack of adequate insurance and/or indemnification if it continues will inhibit the growth and development of the American atomic industry. Lack of trained men is a major but diminishing problem.

Technical problems. The past few years have seen rapid advancement of the basic physics and chemistry underlying reactor technology. Unfortunately, the advances in basic metallurgy have not been able to keep ahead of the increase in demand for nuclear materials. This is particularly true of materials needed for conditions of use involving especially high temperatures and pressures, or especially corrosive materials. A whole new technology has had to be developed to produce and use zirconium, which has many of the advantages of stainless steel but about one-tenth the capture cross section.

There is also a special need for materials of high neutron capture for use in controls. Such little known materials as boron, cadmium, and hafnium are used for this purpose.

Fuel-element fabrication is still a custom operation. The useful life of reactor fuels is not clearly established. This is set by one or more of the problems of irradiation damage, corrosion, or reactivity. The present state of knowledge about irradiation damage is based on limited results from successful experiments with uranium metal samples exposed to over 3,000 Mwd/ton of irradiation and uranium oxide samples exposed to over 10,000 Mwd/ton. In both cases the number of samples tested has been too small to give good statistical data. We can expect to obtain reliable operating data on fuel life only after several



FIVE PREDICTIONS FOR NUCLEAR POWER GROWTH. References are Lane (NU Oct. '54, p. 65); Knowlton (Electrical World AIF (Growth Survey, 1955); Lane (NU Oct. '54, p. 65); Davis (Engineering News Record, April 21, 1955, p. 21); Knowlton (Electrical World, vol. 141, No. 16, p. 108, 1954); General Electric (quoted in McKinney Report). Curves supplied by Floyd L. Culler, Jr., ORNL

power reactors have been in operation for an appreciable period of time.

It is clear from these and numerous other examples that could be cited that the materials problem is an important one in reactor technology. It should also be clear that it is not one in which rapid progress can be made. Much time is required to evolve new materials for new uses especially when these materials must be tested over long periods of time. Much of the discussion about delays in individual reactor projects and the long time scale for the development of reactors indicates a lack of understanding of this fact.

It is extremely important to develop materials and techniques for using plutonium in power reactors. There are many advantages in using slightly enriched fuel, in using plutonium after reprocessing, and in avoiding permanent reliance on enrichment plants. This program, now in its early stages, will become more important.

Economic Problems

Nuclear power is not yet competitive in the United States. Furthermore, it is extremely doubtful that it can meet the stiff fossil-fuel competition in ten years.

There is promise, however, of substantial reductions in both capital and operating costs of reactors after the present transition period. One way of bridging this period of low economic incentive at home is to sell reactors abroad under conditions that will enable the United States to be fully informed of the operating experience that results. The cost of power in reactors of the pressurized-water or boiling-water types, the only two far enough along in the U. S. to be suitable for sale abroad at the present time, is estimated at 12–14 mills/kwh when costs have been stabilized after the initial shakedown operation. While quite high in the U. S., such costs are competitive in a number of countries where fossil fuels are costly.

Capital costs. To attain economic nuclear power in the U. S. substantial reductions must be made in capital costs. Building prototype plants is an important step in accomplishing this. In this area as in many others we can learn by doing. Experience with production plants, such as those at Hanford and Savannah River, has amply demonstrated that the performance rating of a nuclear plant can be greatly increased without any significant increase in capital cost. The same is to be expected with nuclear electric-power plants. For such improvements nuclear power plants must be built and operated by people who really understand the problems, are able to assess the true capability of the plant, and are directly interested in the reduction of capital costs. Under best conditions such improvements will take time. Each generation of new nuclear plants requires at least five years for the construction and initial operational phases.

As the nuclear-equipment business grows, manufacturing volume will increase and both designers and manufacturers will gain experience that should lead to manufacturing-cost reductions. There is a considerable difference between specifications for many principal components of nuclear plants and specifications for conventional equipment. As a result the production of equipment for the initial nuclear plants is being carried out on a costly, job-shop basis.

Operating costs. In addition to a reduction in capital costs there must also be a reduction in power production costs. Fuel cost is the major item. In fact, it is fair to

W. K. Davis
L. H. Roddis, Jr.
C. D. Goodman

From left to right, the director, deputy director and assistant director for technical operations, Division of Reactor Development, U. S. Atomic Energy Commission.

say that economic nuclear power in the U. S. will require an order of magnitude reduction in fuel costs—inventory, burnup, fabrication and processing.

Major reductions in fabrication costs and somewhat lesser reductions in processing costs will certainly be achieved as a result of technical advances during the next few years. There will be some reductions in costs of fuel inventory and net fuel burnup. Total fuel costs for the first generation of nuclear power reactors—that is, those that will start operation between 1960 and 1964—may range from 3 to 10 mills/kwh. Ultimately, it is expected that nuclear fuel costs may be reduced to less than 2 mills/kwh in the United States.

Plans

The AEC's civilian-power-reactor program began early in 1954 with an experimental program based on five power-reactor concepts: pressurized water, boiling water, sodium graphite, fast breeder, and aqueous homogeneous. This program included the construction of a large experimental pressurized-water reactor (the Shippingport PWR) begun earlier and smaller reactor experiments for the other four concepts. An extensive ancillary program of development in the fields of materials and metallurgy, physics, heat transfer, and fluid mechanics as well as component development and testing was also included. This original program has expanded considerably. Now work on organic-moderated and liquid-metal-fueled reactor experiments is proceeding and development work is under way on heavy-water-moderated, high-temperature gas-cooled, and fast molten-plutonium-fueled concepts as well as on still other concepts. Additional types will be added in the future, particularly as development of other types moves into more advanced stages—or is terminated.

Greatly increased emphasis is being placed on three technological areas: use of plutonium as a power-reactor fuel, chemical processing of power-reactor fuel elements, and the understanding and improvement of safety characteristics of reactors. Increased emphasis is being placed on the basic scientific and engineering fields in which future improvements can be expected to originate.

AEC responsibility. The AEC plans to continue to take responsibility for providing the technological basis for the establishment of the nuclear-power industry. However, it is expected that industry will, in various ways, increase its participation in and responsibility for the developmental phases.

Much of the development work supported by the AEC has, of course, been done under contract by industry. This policy will surely continue probably with increased emphasis on contracting for reactor development with industrial companies that not only can make a real contribution to the development along industrial lines but also can produce reactors on an industrial basis when the development has been accomplished.

The AEC intends to carry reactor developments through the reactor experiment stage and to insure that necessary prototypes are constructed. It is believed that industry will undertake the construction of prototypes with their own funds. We firmly believe that this is a much more effective method than that of government-funded construction and operation.

Which reactor types? There is no intention of developing all types of reactors that can conceivably work or even all types put forward as having promise of economic success. It is necessary to make the best possible choices for successful development in the U. S. and to push these choices as rapidly and effectively as feasible. It would be very easy to diversify the U. S. effort to an extent that all available resources would be insufficient for a satisfactory program. It is a matter for concern that so many different concepts are in various stages of development and that there is such great pressure to add many additional concepts.

It is particularly easy to feel that some other reactor concept about which much less is known may be more attractive when the concept being worked on is encountering formidable difficulties. It seems to be true in the reactor business that the less is known about a reactor the better it looks. Nevertheless, it is also true that not all reactors carried through the early development stages will be found to warrant the construction of reactor experiments or prototypes. Further, it is the nature of development projects that changes and delays are met that must be accepted if the over-all development is to proceed.

There is great emphasis today on scheduling and planning and on making precise estimates. There is great emphasis not only on adding new reactor concepts to the program but also in pushing ahead on those already in the program regardless of their promise or stage of development, and regardless of what further developments may show. These pressures are clearly inconsistent with a rational development program. There is a great need for a flexible approach to the many problems in the realization of nuclear power in the U. S., particularly in the areas relating to the transition from governmental to industrial financing.

There seems to be an impatience with the rate of progress of the development program, the major part of which was begun only three years ago. There is an urge to dash ahead and to find shortcuts—usually by rushing off in some entirely new direction altogether. There does not seem to be much appreciation of the fact that by its very nature the development and improvement of reactors takes a substantial period of time. Where the performance of materials is the critical area, it is simply not possible to accelerate the development progress for devices such as reactors in which the materials must perform usefully for decades—and where failure has such devastating economic effects and can be a threat to safety.

As painful as progress may appear to be, and we do not believe that those who are familiar with the real progress made during the past three years view it so, it cannot be greatly accelerated nor can the problems which impede progress be bypassed in favor of expedients. By succumbing to this temptation we may only undermine the possibility of successful prosecution of the program under way—a program which it is planned to carry forward as expeditiously and as effectively as possible.

Cost estimates. A further source of trouble with shortcuts is found when cost of power figures are quoted widely as showing that some reactor type is superior to another. This is an area where even well informed people are misled because the assumptions in arriving at any power-cost figure are so much more difficult to uncover and remember

predictions

Here are some predictions based on what we consider to be the most probable developments in the civilian reactor program. Assuming that we have a decade of peace and that the reactor-development program is carried out in an effective and successful manner, we expect by 1967:

Continued improvement in the technology of pressurized-water and boiling-water reactors, including decreased fuel-fabrication costs, increased performance rating, the use of more conventional materials and components, increased longevity of fuel, a decrease in the multiplicity of safety devices.

Significant decreases in both capital and operating costs of the foregoing reactors.

Nuclear power plants in operation in the U. S. that will be economically competitive over their useful lives for power and other applications as well.

Approximately 7,500,000 electrical kilowatts of nuclear power plants in operation. This will be 2.6% of the installed electrical generating capacity in the U. S. We anticipate that ⅔ or more of this capacity will be PWR- or BWR-type reactors with the balance distributed among the other types of reactors now under development. Most of the plants will be very large, 200–400 Mw(electric).

About 5–10-million Kw (electric) of nuclear plants of the PWR/BWR type based on U. S. design in use abroad. Most of these plants will be well above 100 Mw in size.

Most domestic and foreign reactors will be enriched. U^{235} and Pu^{239} will be used as enriching materials on increasing scale. There may be some strictly natural-uranium reactors.

Safety of nuclear power plants established to the point where site selection will no longer be of real concern to the public.

Nuclear power an integral part of our industrial economy. The role of government will have shifted to more of a purely regulatory nature.

Greatly increased interest in nuclear energy for heating and process uses. Nuclear propulsion for merchant ships will be near economic utilization.

Demonstrated scientific feasibility of controlled thermonuclear reactions, but the development of economic utilization will be in its early stages.

than the summary figure of so many mills/kwh. The simple truth is that the assumptions of amortization period, interest rate, allotment of development costs, taxes, capitalization method, fuel life, power rating, etc., are much more determining than the choice of reactor type. There are no real shortcuts to factual knowledge in these areas or to the use of common bases of comparison. Today the widespread credence placed on cost-of-power estimates without adequate understanding of their basis is often causing unreasonable pressures to place emphasis on one reactor type over another.

Power-demonstration program. The AEC established what it called the Power Demonstration Reactor Program early in 1955 to stimulate industrial development and construction of prototype power reactors. It is the objective of this program to provide sufficient assistance and encouragement so that the necessary larger-scale, semi-commercial reactors will be constructed under the most desirable conditions for further economic development at such time as the technical development for a particular type has reached the stage where construction is logical and prudent. It is likely that some reactor types will not show sufficient promise to justify such construction after earlier development has been carried out.

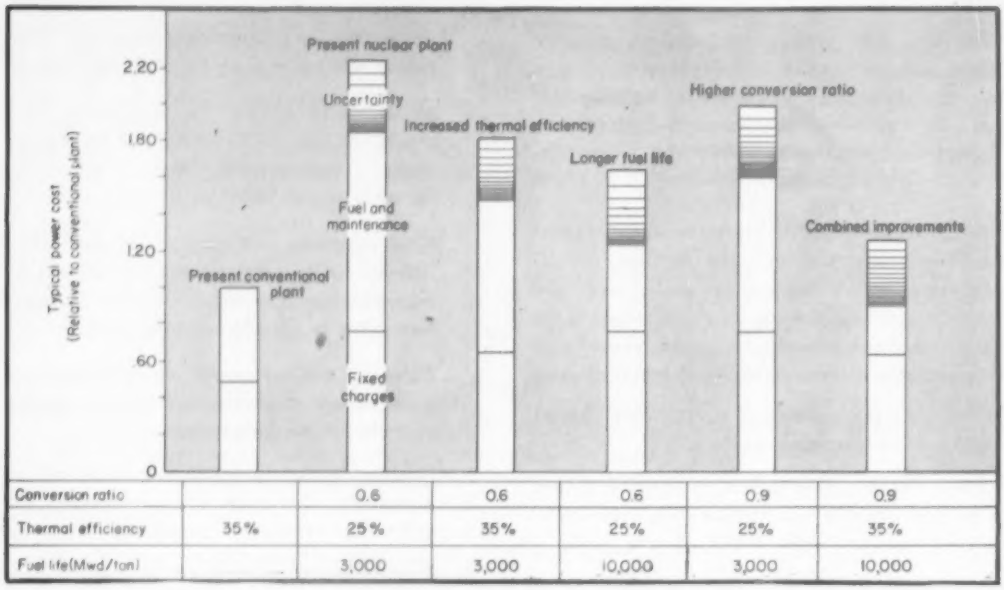
Three specific invitations have been issued under the Power Demonstration Reactor Program. The first and the third were directed towards reactors of any size while the second was directed towards reactors of 5–40 electrical megawatts of particular interest for use abroad and by publicly-owned power groups.

The Power Demonstration Reactor Program is not directed toward achieving any particular size or kind of nuclear power industry in the U. S. Its purpose is development. While variations and improvements on types of reactors already under way have been considered to qualify for assistance, simple duplication would not.

On the other hand, this program has not been intended to support the over-all development of wholly new types of reactors—types that might require several years of research and development before prototype construction could logically be undertaken. It is felt that if such development is deserving of support this should be done as a regular development under contract with the AEC rather than as a part of this program.

Private-industry program. There is also a growing independent industrial program. This growth has been nothing short of spectacular. Three years ago there was no private industrial reactor program at all. Now not only are there several full-scale reactor prototypes under way in the hands of private industry, but there is also a large and growing private research-and-development program. In addition, private facilities have been built and are under construction for carrying out research and development, for testing reactors, for fabrication of fuel elements, for the manufacture of a wide variety of components, and for the provision of numerous services.

It is probable that the variety of services performed on an industrial basis will increase. Industrial chemical processing seems assured once there is sufficient volume of business. Other steps such as the reduction of uranium hexafluoride to metal will be provided by industry. Competition will reduce current high prices.



Conversion ratio		0.6	0.6	0.6	0.9	0.9
Thermal efficiency	35%	25%	35%	25%	25%	35%
Fuel life(Mwd/ton)		3,000	3,000	10,000	3,000	10,000

FIG. 1. Comparative power costs with current conventional plant and present and future nuclear plants. Bars 3 to 5 show effects on present nuclear-power costs of improvements in thermal efficiency, fuel life and conversion ratio, respectively, and last bar indicates cost one could achieve with simultaneous improvement in all three

POWER REACTORS

2. economic trends

By CHAUNCEY STARR

IN SPITE OF THE FACT that there does not exist today an operating nuclear reactor that is economically competitive with fossil-fuel plants, the past decade has been marked by the successful completion of experimental reactors involving many bold and radical technical developments and has established the feasibility of nuclear reactors for research, power and propulsion.

The early consideration of civilian power reactors revolved about the dual-purpose reactor, in which plutonium for the military was the primary product and electrical power was secondary. It appeared that the income from the sale of electrical power from such a high-temperature reactor might more than compensate for the additional cost of construction as compared with a low-temperature plutonium producer.

Unfortunately for the dual-purpose concept, the maximum size of a single power source that might be instantaneously lost from a power network under scram conditions was considerably smaller than the desirable size of a low-temperature plutonium producer. As extremely large single-purpose reactors cost less per megawatt of heat than the smaller permissible electric-power producers, the savings in plutonium-production cost through dual-purpose operation was decreased. In addition, constant improvement in production costs for the existing single-purpose plutonium plants made the merits of the dual-purpose approach very dubious.

Enriched fuels. In these early plans for nuclear-power development the use of enriched fuels was not seriously considered because of the expected high cost. In late 1948 Karl Cohen pointed out that the cost of isotope separation for moderate enrichments is not unreasonably expensive and that therefore slightly enriched reactors should be seriously considered for power production. Because of the prevailing opinion that plutonium would always have a very high value for military purposes, slightly enriched dual-purpose reactors became the immediate study objective.

At about the same time Edward Teller independently suggested slightly enriched reactors for naval propulsion.

This became the first seriously considered single-purpose power producer, as it appeared that the military use justified the cost.

During this period the military stockpile of fissionable material grew rapidly and it subsequently became clear that a long-range nuclear-power industry would not be soundly based if it depended on the military procurement of plutonium for its economic justification. As a result the power-only reactor has been established as the basic goal in the development of power reactors.

Breeders. Another early concept that heavily influenced the course of reactor development was the role of breeders. In the early postwar years uranium ore was available from a limited number of sources. When one compared this availability with the requirements of future world-wide power needs, it appeared unlikely that uranium would be in sufficient supply unless it was utilized completely through the breeding process. In the subsequent years the scope of uranium exploration has been so great that the availability of uranium ore has been increased by many fold.

It appears now that the breeding process is not mandatory for the initiation of world-wide nuclear power

Breeding may not be an economic necessity for several decades.

Changing economics. Concurrent with the shifting philosophy guiding the development of nuclear power reactors, there have been economic changes of equal significance. These have affected the choice of reactor approach. For example, the investment in fuel inventory was originally considered in the category of capital investment and thus carried fixed charges at 12–16% of the inventory cost. At the present time, the leasing policy of the AEC permits these to be carried at 4%.

Similarly, heavy water was estimated to cost in the range of $100/lb in the early period as compared with the present AEC quoted price of $28/lb. From time to time the AEC has offered to waive the interest charges for fuel or heavy water under temporary and special circumstances. The price of plutonium has ranged from several hundred dollars per gram to the range of $30–45/gm presently quoted by the AEC. Zirconium, an expensive curiosity a decade ago, is now commercially available at $7/lb.

Such drastic price changes on reactor ingredients can completely alter the choice of the "best" reactor type. For example, a substantial cost reduction in beryllium metal would result in a new family of reactor types paralleling the present graphite-moderated reactors. In addition to the specific items mentioned above, there remain several areas under the control of the AEC in which price alterations might drastically affect the economics of reactor performance. The chemical-reprocessing costs recently established by the AEC are typical of the significant cost areas that might be subject to sharp change from time to time.

Until a nuclear-power industry of sufficient magnitude and stability has been established, many of these broad planning and economic considerations will not be stabilized. For this reason it is probably not desirable to use present-day criteria as a basis for severely limiting the number of reactor development concepts.

Let us consider the variety and significance of the principal problems associated with present reactor developments. These include the composite reactor-fuel-flow cycle for both heterogeneous and homogeneous reactor concepts with either aqueous or pyrochemical (nonaqueous) processing techniques. The aqueous-chemistry cycle is the originally developed approach, and its costs are fairly well known. Pyrochemical reprocessing has been under recent development and has not yet achieved a practical demonstration. Fundamentally, the concept is similar to that used in the manufacture and purification of steel through the slagging process.

Estimated costs of large nuclear power plants do not presently appear to be sensitive to the specific reactor type proposed. Although major differences in capital costs may develop as these plants are built in their second and third generation, it is not now apparent just how these will arise. It is of interest, therefore, to examine the technical factors that affect the performance of a plant and could directly influence the cost of power. Some of these are illustrated in Fig. 1.

The necessity for engineering development in the performance and reliability of components of nuclear reactors and for the reduction of capital costs is evident.

Emphasis must be put on the development of materials and technologies that will permit improvements in fuel elements, temperatures, and conversion ratios

Operating costs. One of the largest areas of uncertainty and possible improvement is in the operating costs of the nuclear plants. Probably the most uncertain operating cost is maintenance. Experience on repair and servicing of nuclear plants has been limited, and in general maintenance techniques have been tailored to special circumstances involved in particular cases. Difficulties in handling highly radioactive components are so great as to engender large costs. These may come from two sources—(a) loss of income due to prolonged shutdown and (b) high maintenance, equipment, and labor costs. Those nuclear plants that have already been operating

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for some time have, in general, been trouble-free, but where there have been failures due to corrosion, fuel element difficulties, and the like, repairs have involved prolonged and costly operations.

Because of the uncertain and intangible aspects of the maintenance costs for nuclear plants, their ultimate economic significance is difficult to establish. However, it appears likely that one of the principal features of nuclear power plants that may determine their future desirability and over-all competitive status may be the ease with which repairs and maintenance can be accomplished. This may become a major design objective generally.

In certain specific applications the tangible and intangible aspects of maintenance and repair are now predominant criteria in the choice of a plant. For example, under maritime conditions the consequences of a nuclear-plant failure and the associated logistics of its repair at sea are likely to be of prime consideration in the choice of a plant. In a smaller degree similar emphasis may exist in remote-site applications.

Component life. Another aspect of nuclear-power-plant performance on which very little experience exists today is the life of reactor components. It is clear that in the evaluation of competitive economics of nuclear plants there is no empirical basis for assumption that the lifetime of such plants will be the same as that of conventional plants. It should be recognized that present experience is limited in general to a small number of years. Those considerations that are pertinent to component lifetimes of 20 years or more may not be evident in short-time operation. However, the experience to date in this field gives every cause for optimism concerning the durability of nuclear plants.

Fuel costs. An important and as yet uncertain area is the over-all fuel cost for nuclear plants. It is not yet clear what the actual costs of recycling will be on a completely commercial basis in which the AEC is not involved. Presumably such an industrial basis for recycling fuel will be established in the future.

Development of pyrochemical reprocessing techniques will probably be intensified in the near future

When one considers fuel cycles involving the use of plutonium or U^{233}, the specific activities of these fissionable materials are so great as to render necessary remote refabrication and handling of fuel. Under such circumstances, the only purpose of processing spent fuel would be to remove those fission products that have a deleterious effect on the physical properties and neutron losses of the fuel element. Reduction of the fission-product content in the spent fuel element by a factor of 10 (removal of 90% of the fission products) would probably be sufficient. One of the advantages of aqueous chemical processing has been the ease with which million-fold decontamination can be accomplished in order to permit manual refabrication of fuel. However, in the event that plutonium and U^{233} cycling is involved, this advantage is no longer pertinent, and the use of pyrochemical methods becomes more appropriate. Pyrochemical methods permit easy decontamination by the required factor of 10, and have the further advantage that fission products removed are left in a concentrated form, as compared with the dilute waste products from an aqueous chemical plant.

The most direct way to minimize reprocessing costs is development of long-life fuel elements. The behavior of metallic elements under prolonged radiation has not as yet been sufficiently explored to permit assurance that long-life metallic fuel elements can be developed. There is some evidence that the use of oxide fuels rather than metallic fuels will permit prolonged radiation exposure.

If long-life metallic elements can not be developed, the use of oxide or other ceramic elements may become a necessity for economic reasons

On the other hand the appreciably lower density and thermal conductivity of oxide fuel elements may result in a somewhat larger reactor core.

None of the reactor concepts under present development has optimum characteristics for minimum power costs. In Fig. 2 is shown the present-day distribution of reactor types and fuel elements with relation to the principal technical characteristics that have been discussed. The future results of research and development may materially alter the relative positions. This is particularly true in the matter of conversion ratios as these are very sensitive to materials of construction and design approach. It is probably least true with reference to operating temperatures of the reactors since these are chiefly determined by the coolant. Fuel-element lifetime will be affected primarily by the fundamental physical properties of the fuel-element materials. In this regard the effects of fission-fragment damage and fission-product release are of major interest. It has always been recognized that liquid fuels avoid this type of problem and permit the desirable long fuel lifetime.

Actual cost of power from any of these reactor approaches involves a wide variety of cost elements in addition to those determined by the technical parameters illustrated. Practical economics associated with size, location, and nature of the nuclear reactor and its supporting facilities can make major differences in the final power cost. Location and size of chemical-processing plants, cost and nature of fuel-element shipment, and requirements for waste disposal and reactor containment are typical of cost elements that can determine the final economics of nuclear power.

The next decade. Future cost reduction will surely come from a combination of effort in a variety of areas. As has been the history of the conventional fossil-fuel steam plant, a painstaking improvement in operating temperatures, operating techniques, equipment costs, reliability, and all other basic cost elements must be undertaken. Although many of these factors can be influenced by improved engineering design, it presently appears that for nuclear plants most of these require the development of improved materials. Many of these materials problems are similar to those in conventional high-temperature

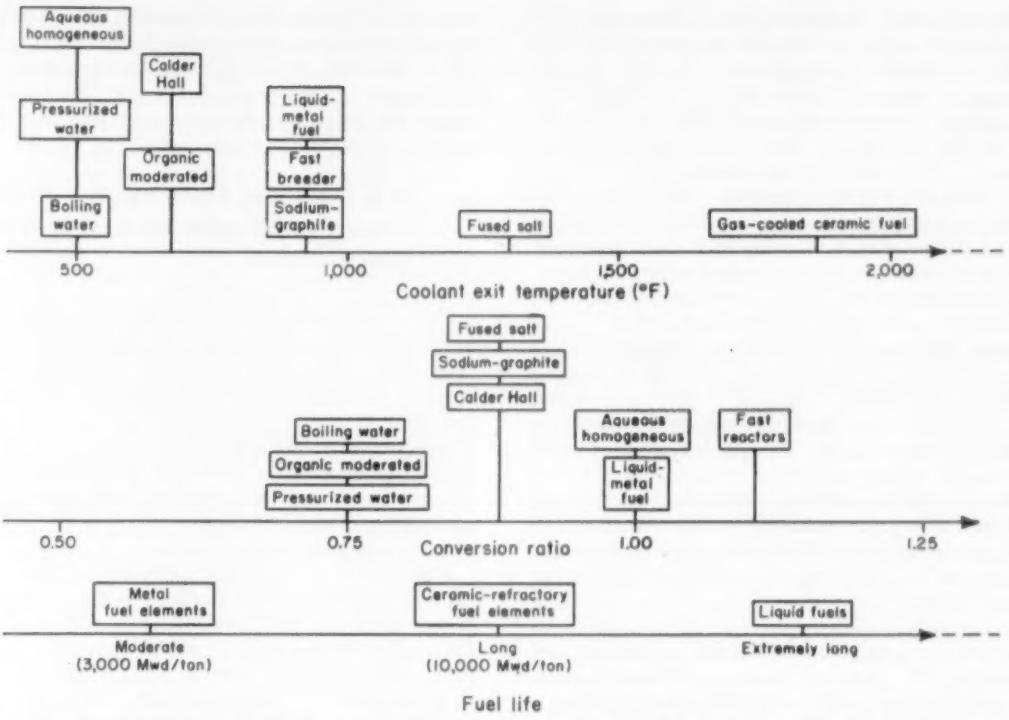

FIG. 2. Coolant temperature, conversion ratio, and fuel life are principal cost parameters. Here are their approximate values in today's reactor concepts

fossil-fuel plants. The successful development of high-temperature, corrosion-resistant structural alloys with low neutron absorption can result in a significant improvement in a variety of present and future reactor designs.

Ceramic fuels. The combined effects of high temperature and prolonged irradiation have not yet been thoroughly determined, but with the promising results to date, every effort in the further investigation of ceramic elements is warranted. Metallic fuel elements appear to be more uncertain with regard to their high-temperature long-time stability. Consequently, much remains to be done in the investigation of uranium and thorium alloys in order to improve this area of performance. It should be remembered that for equal fuel-element life, there are advantages associated with the metallic fuel element because of its higher density and thermal conductivity.

Liquids and Slurries. The long "life" and neutron economy of liquid fuels must be compared with the difficulties associated with their use. Because of the corrosive aspects of the liquids now used and the fact that high-level radioactivity is circulated throughout the coolant system, the liquid-fuel reactors have relatively costly chemical-engineering plants associated with the reactor core. It may be possible that in the next decade the engineering problems and costs will be satisfactorily resolved. The basic advantages of the liquid fuel are great enough to justify intensive effort in this regard.

So far slurries and suspensions have been studied only a little both abroad and in the United States. The slurry substitutes the problem of erosion for the corrosion difficulties of liquid fuel. It has the additional difficulty of maintaining controlled distribution of the suspended fuel.

The slurry has many of the fundamental advantages of liquid fuel and warrants further study

Improved utilization of nuclear fuels will result from reactor-core designs with nonuniform radial fuel loadings. In these designs all fuel assemblies will produce maximum power regardless of location in the core. This will eliminate the need for individual orificing of each fuel assembly and result in uniform burnout of fuel. In addition, core designs will be studied wherein fuel concentration will be varied along the direction of coolant flow so as to maximize the power-removal capability of each element.

Conversion. Conversion ratio will get more attention following engineering development of the first reactor models. Improvement can be achieved through reduction of neutron-absorbing structural materials, addition of breeding blankets, use of nonpoisoning control elements, and optimization of core configuration with respect to neutron economy. At present these considerations have been generally sacrificed by the cautious nature of structural design of core and components. As greater experience and confidence is developed one can expect consider-

able improvements. As increased emphasis is placed on neutron economy, it is possible that a greater interest in intermediate- and fast-spectrum reactors may be evidenced.

This can be particularly pertinent to the Th-U^{233} fuel cycle. As the neutron yield of U^{233} may be independent of neutron energy, an intermediate spectrum offers improved neutron economy as a result of the reduced neutron losses to the reactor structure. As with the other elements of reactor performance, materials development can play a significant role. In particular, the development of high-temperature corrosion-resistant alloys of aluminum, magnesium, and zirconium may make a contribution in this area.

Thermal efficiency. The value of high-temperature reactor performance to achieve higher thermal efficiencies may increase the interest in future reactors that use liquid metals and gases. One can expect increased emphasis on such liquid metals as sodium, bismuth, lead, and tin, which are of special interest as reactor coolants. It has been evident that handling of liquid metals is becoming less troublesome as experience increases. Since liquid metals permit use of temperatures as high as steam turbines can accept, intensive development of reactors using this type of coolant is likely.

In first-generation nuclear power plants major elements of costs arise from ancillary engineering, equipment, and construction. In particular, reactor safety and containment, waste disposal, and fuel handling give rise to costs that may not be such an essential ingredient of future generations of nuclear power plants. Absence of sufficient experimental information and operating experience has caused these aspects of nuclear-plant design to be treated in an extremely conservative manner. The AEC has initiated programs to develop this empirical information, and within the next decade the results should significantly reduce these costs.

Maintenance. The cost of maintenance of future nuclear power plants can only be guessed at now. There have been only a small number of major reactor failures, and these have been handled without organized preparation in advance. Although much has been learned from the emergency action taken under these circumstances, the costs and time associated with these past events would not usually be acceptable in electric-power plants. For this reason, the maintenance of large-scale radioactive systems must be given detailed engineering study, and methods and equipment for simplified handling of such maintenance problems must be developed. This problem is generally realized by nuclear plant designers, and it can be expected that within the next decade the design features of nuclear plants will permit simplified maintenance techniques.

Future trends in reactor types will follow several major streams of effort, course of which will be determined by the different end uses of the reactors. Military applications of power reactors have highly specialized end purposes and associated design criteria. Such programs as the nuclear-powered submarine and nuclear-powered aircraft are major sources of reactor development, technology, and operating experience and serve as a principal stimulation in many new areas of engineering. The special characteristics of military reactors are so intimately related with their objectives that they do not render themselves to generalizations and will not be discussed further here. Nonmilitary nuclear power plants can, however, be placed in the following general categories: large central-station plants, small independent power sources—either portable or stationary, plants for propulsion purposes; process-steam plants, process-heat plants, and radiation plants.

It is likely that future trends will enhance rather than diminish the lead held by enriched reactors

The line of development within the U. S. will be directed to central-station power plants principally of the enriched type. The principal advantage of the natural-uranium approach is simplification of the fuel cycle and the lower fuel costs that would result if a long-life, once-through natural-uranium fuel element could be used. As long as the cost of chemical processing is high, this approach has merit. If, however, chemical processing costs are significantly reduced within this next decade, the natural-uranium approach appears dubious.

The program of enriched-reactor development already under way will probably result in sufficient cumulative experience within the next few years to permit a preliminary evaluation of these reactor concepts. With the great multiplicity of factors involved in these considerations it is difficult to project a trend. There are inherent benefits associated with the use of liquid metals.

It is likely that within the next decade an increasing emphasis on liquid-metal-cooled reactors will become evident

However, it is not yet clear that the advantages of liquid metals can balance their additional capital costs.

A second line of development will probably emanate from abroad as a result of efforts to develop reactors that do not rely on the output of an isotope-separation plant. This will result in a family of natural-uranium, heavy-water, or graphite-moderated reactors probably involving the use of plutonium "feedback" in order to get the benefits of low enrichment. Such reactors will undoubtedly be in operation within the next decade. Associated with this but on a longer time schedule will be the construction and development of true breeders with emphasis primarily on the fast plutonium breeder.

A third line of development will result from the interest in small independent power plants that can be operated with a minimum of maintenance and technical skills. In such reactor applications, thermal efficiency and conversion ratio are of secondary significance. This type of application includes the package power plant for use in remote locations, the maritime power plant, and power plants for underdeveloped countries. It is likely that this line of development will carry on the trend started by the Pressurized Water Reactor, the Boiling Water Reactor and the Organic Moderated Reactor. The emphasis on simplicity, reliability, and safety will ultimately determine the design of these plants.

Within the coming decade, an experimental gas-cooled reactor using a closed-cycle-gas-turbine power plant will

probably be placed in operation for use as a small independent power plant. The compactness and high efficiency of the gas-turbine cycle over a wide load range make it particularly interesting for these applications. The gas-cooled reactor appropriate for this application requires a working fluid at a higher temperature than any of the power reactors in the present program. Such a reactor might be the forerunner of large high-thermal-efficiency central-station plants.

A fourth line of development will begin to appear when the cost of nuclear heat begins to approach that from conventional fuels with the consequent application of nuclear reactors for the production of process steam. As the economics and technical requirements for process-steam production differ from that of electrical power plants, nuclear reactors for this purpose will also differ. Process steam is customarily circulated in many areas of industrial plants and would have to be safeguarded against radioactive contamination.

A fifth line of development—process heat reactors—will be initiated at such time as high-temperature gas-cooled nuclear reactors become feasible. These can be a direct consequence of the development of ceramic fuel elements with the requisite physical, thermal, and radiation stabilities. A large field of high-temperature chemical reactions might become economically interesting if high-temperature gases could be produced at low cost from nuclear reactors. Because such reactors would operate in a temperature domain beyond the realm of present industrial experience, it is uncertain that this type of application will come to fruition within the next decade.

The sixth line of development could result from the advent of a sizable market for radiation in industrial and food processing. It has been pointed out many times that nuclear reactors produce radiation of a heretofore unavailable intensity. The process industries are now examining the possible effect of bulk radiation on their products. If such a market for radiation were to develop, it would lead to the optimization of nuclear reactors for this purpose. It is likely that such radiation would have to be free of neutrons in order to be usable. In the case of the homogeneous reactors, the fission-product gases would become available. In the case of the heterogeneous reactors, one could use spent fuel. With either reactor type, it is possible to circulate a fluid that would be activated and used as a radiation source. In this regard, some of the liquid-metal coolants already have this characteristic. The shielding of a radioactive liquid-metal-coolant circuit is an additional cost burden in an electric-power plant. However, this could become a virtue if this coolant were used for radiation processing.

Conventional plants. In considering the long-range objectives for the nuclear-power field, it should not be forgotten that the performance of conventional fossil-fuel plants is not stationary but rather constantly improving. A recent study of this subject* indicates that in ten years it is expected that conventional steam plants will be operating at 1,250° F and 5,000 psi. It is also of interest that ten years from now the maximum size of an individual unit may be as high as 600 electrical Mw and may cost about $150/kw installed. The benefits of increased size as a means of lowering unit cost may apply to the conventional plant as well as to the nuclear plant. With this type of development projected for the conventional plant, the degree to which the nuclear plant will have to be improved may be considerably greater than anything anticipated now.

A look ahead. Prognosis is difficult in the field of nuclear power; still there are some trends that look probable.

Within the next decade there will be more central-station reactors built abroad than in the U. S. because of the greater need and economic justification

There will undoubtedly be some special locations even in the United States where nuclear power stations will appear desirable. The nuclear propulsion power plant for maritime application may become economic within the early part of the next decade. This will be especially true if the trend toward large tankers continues. In fact, the maritime application has a good chance of being the first economically justifiable application. In general, one might expect within this next decade that some of the present reactor concepts will have proved themselves inferior and that new reactor concepts not in any present program will arise. In addition to substantial engineering improvements in reactor designs and components generally, the increased skill and familiarity with new technological fields will probably stimulate a greater boldness in engineering design of nuclear plants.

Within the next decade it should be expected that several areas of reactor-fuel-cycle services will be placed on a commercial basis. This is likely to occur in the fields of chemical processing, waste disposal, and fuel fabrication. If a nuclear power plant industry is to exist, the cost of such services must certainly be low.

It should be realized that the present nuclear-power-reactor program is only about five years of age. While the low-temperature plutonium-production reactors span a greater period of experience, their developments have not been primarily concerned with power-generation technology. With this short initial growth period behind us, it is difficult to project the trend lines of development. Many of the reactor concepts included in this past five-year program are just beginning to produce experimental information. Although it is evident now that the present estimated costs of nuclear power must be cut in half to be of interest in the United States, there is every indication that this can be done by intensive development. In this regard, it is obviously necessary to build both small and large experimental nuclear plants to acquire experience and to develop operating components. It is also evident that fundamental work on reactor materials, fuel elements, and coolants needs to be intensified to make significant improvements in the working plants. Applied research in these fields may have as much significance in the attainment of competitive power as the development of our present variety of reactor concepts.

* Harlow, J. H. "Projecting Steam Costs to 1980," *Combustion*, June 1957.

For the Years Ahead—Ten Areas of Progress

1. Nuclear Plant Experience
2. Plutonium Pricing
3. Higher Temperatures
4. Natural Uranium
5. Specific Power
6. Homogeneous Reactors
7. Chemical Reprocessing
8. Oxide Fuel Elements
9. Heavy Water
10. Plutonium Recycling

POWER REACTORS

3. technical problems

By WALTER H. ZINN

POWER REACTOR TECHNOLOGY is a large and intricate subject. Analysis of the present state of the engineering of reactors and an appreciation of how this engineering has developed in the past 15 years readily suggests numerous items and details for which improvement is bound to come. The assignment by NUCLEONICS of a review and projection for this subject on the occasion of the celebration of its tenth anniversary calls for a more selective appraisal of the areas in which development will be most important in the coming decade. Obviously, the statements made herein are expressions of opinion, and it is well to remember that the many programs of research and actual experience will shape the future. In the following, therefore, an attempt is made to identify the areas in which the greatest activity is expected and which are the areas in which greatest progress will ensue.

1 Nuclear Power Plant Experience

During the next ten years, authentic experience in the operation of nuclear power plants will be obtained. To date, improvements in reactor power plants have not come about as the result of experience in operation but have reflected new research results or new design. In the years ahead, we will gain a real understanding of what it means to design, build, and operate a plant under federal government regulations that are of a kind new to the power industry. A period of operation long enough to eliminate many minor technical difficulties will be available, and the recurring question of the attainable plant factor will be answered. The excuse that "it's experimental" will have worn very thin, and the nuclear plants will have been subjected to the same rigorous analysis and testing with respect to performance that fossil fuel plants have been receiving.

Ten years is not a long time to accumulate such experience if one takes into account the fact that plants in which this experience is to be obtained are only under design or have barely begun to be constructed. Especially in the area of fuel-element behavior, time is a very important matter. The majority of reactors planned require long burnup to show reasonable fuel costs. It is the late part of the burnup cycle that is in question, especially for the evaluation of corrosion and radiation damage. Therefore, until several complete fuel charges have been passed through the reactor, the fuel cost remains uncertain. For

most reactors, several years may elapse before all of the fuel charge has been exposed. This means that the accumulation of significant experience will be a slow business.

2 Plutonium Pricing

The operator of a nuclear power plant may be faced with a difficult decision with respect to replacement of fuel. Assume that the fuel element in the reactor has been giving some difficulty because of failures of the jacket. The frequency of these failures and the difficulties encountered in discharging fuel and doing whatever cleanup is necessary are not only an operating nuisance but a direct financial loss. Suppose a new fuel element is developed which promises to remove many of these problems. Can the operator afford to discharge the fuel now in the reactor and take advantage of the new design?

His judgment as to whether he can afford it will be greatly influenced by the price at which he can sell the plutonium contained in the fuel elements already in the reactor. Further operation of the reactor will not add to the amount of plutonium for sale, and if the plutonium credit is substantial, discharge of the old fuel charge and replacement by a new one is more easily justified. Therefore, the $30/gm figure which the AEC has now set, if it were continued beyond 1963, would greatly aid the rapid improvement of fuel elements. Unfortunately, the advantage of a high buy-back price is not available to reactors which produce U^{233}. At the original fuel value prices of $12/gm for plutonium and $15/gm for U^{233}, and for similar long burnups, there is not much choice on economic grounds between the U^{235}–thorium fuel and the slightly-enriched-uranium fuel. The $30/gm figure for plutonium gives a premium of roughly 1.5–2.0 mills/kwh to the reactor producing plutonium and obviously will encourage changes in fuel elements to obtain better performance of that reactor.

3 Higher Temperature Operation

The past ten years in the United States will no doubt in the future appear as the time during which the light-water-moderated reactor received the greatest development. The number of pressurized-water and boiling-water reactors which are expected to come into operation bear witness to this point.

However, it is already well realized by the power industry that the light-water reactor has severe limitations with respect to ultimate cycle efficiency. It may be that the disadvantage of the low temperature will be solved satisfactorily by the use of fossil-fuel superheaters. Other solutions have been suggested, such as a reactor in which steam is produced and is superheated in the same reactor, or a central-station plant in which steam is generated by one reactor and is superheated by another reactor of a different type. The demand for steam of more nearly conventional quality, however, will persist and will encourage the development of reactors which are not limited by using water as the working fluid. In the next decade in the U. S., therefore, sodium-cooled and gas-cooled reactors are sure to receive further development, and construction of large-scale nuclear power plants with these coolants will be accomplished. The temperature of the coolant in large-scale plants will not be phenomenally high, 900°–1,000° F seems to be all that is to be expected. The steam conditions obtainable with 900° F sodium or gas are a marked improvement over what seems to be obtainable with 600° F water.

4 Natural Uranium

Several types of plants that can be fueled and operated on natural uranium or near-natural uranium will come into operation in the next decade. These reactors will discharge fuel whose U^{235} content is so low that the value of the discarded U^{235} will be negligible. While these reactors will be operable on natural-uranium feed, there may be an advantage in using slight enrichment to obtain even a lower fuel cost than what can be obtained on natural uranium alone.

Whether or not this actually will take place depends on the situation with respect to radiation damage and corrosion. If, for instance, a reactor fuel is limited to an exposure of 5,000 Mwd/ton by reactivity loss when the enrichment is natural, but can be exposed to 8,000 Mwd/ton with an enrichment of 0.85%, it certainly is economically advantageous to do so. Without actually operating a natural or near-natural uranium reactor and without obtaining long-term experience with exposure of fuel, it is not possible to guess which will terminate the exposure—radiation damage, corrosion, or loss of reactivity. Improvement in the performance of fuel elements is to be expected. This will shift the emphasis to schemes for conserving reactivity.

Under the present schedules for the use of fuel and the AEC's proposed schedules for chemical processing, natural uranium feed promises a lower fuel cost than any other fuel. This lower fuel cost will be important only provided the capital cost of the machine for burning natural uranium is not significantly different than the capital cost of a machine for burning enriched uranium. Such cost comparisons will be meaningful when construction experience for both types of reactors has been obtained.

5 Specific Power

In assessing the potential performance of a reactor, it has been customary to place a fair amount of emphasis on specific power. Generally speaking, it has been considered

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that a reactor which has a specific power of 50 Mw/ton of fuel would be a better bet for economic power than one which has a specific power of 5 Mw/ton of fuel. Typical examples of specific power are as follows: Shippingport, 10 Mw/ton; EBWR, 3.3 Mw/ton; Yankee Atomic Electric, 16 Mw/ton; Dresden, 10.5 Mw/ton; SRE, 7.5 Mw/ton; Chugach, 4 Mw/ton; HRE-2, 917 Mw/ton; Calder Hall, 1.39 Mw/ton. The range is considerable. The basic assumption is that high specific power means a smaller volume of core and therefore less capital investment. It also means that inventory charges and fuel fabrication capital charges are lower.

But a single measure such as specific power is an oversimplification. To get high specific power, it may be necessary to use coolants or operating conditions which themselves bring large capital expenses. Let us suppose that high specific power is obtained by having the fuel in a homogeneous form, and suppose it is circulated throughout the primary circuit; the primary circuit is now not only highly radioactive but, in addition, its metal parts are activated by delayed neutrons. The demand for integrity is very great. It is not possible to say without the experience of building and operating such a plant that the high specific power thus obtained is economically worthwhile. The answer depends on the details of construction and operation, and these details are not available for evaluation unless large-scale experience provides them.

Gas-cooled reactors generally, like Calder Hall, have low specific power. This may not be a fatal handicap if thereby a primary circuit is realized which is essentially nonradioactive and which is constructed of materials no more exotic than carbon steel.

A final point with respect to specific power concerns the fact that high specific power and high power density usually occur together and can result in a safety situation distinct from the case of low power density. A judgment as to the effect of safety considerations on the relative economic attractiveness of reactors must then include an evaluation of the cost of the measures taken to provide adequate safety. The conclusion is inescapable—that evaluating a reactor concept on the basis of a few parameters, such as specific power or power density, might lead to conclusions not supported by actual experience. Fortunately, the U. S. program includes reactors whose ratings fall all along the possible spectrum. The next ten years ought to provide experience which will enable the selection of those parameters which, in fact, are most decisive in determining power costs.

6 Homogeneous Reactors

The great attractiveness of the homogeneous reactor whether it is of the aqueous variety or the liquid-metal variety lies in the simplicity of the complete fuel cycle. The designs of the plants themselves are not notable for their simplicity; for instance, the number of lines, valves, and instruments associated with an aqueous homogeneous reactor is not less than the similar items for a boiling-water reactor. It is the freedom from the expense and complexity of fabricating fuel elements, inserting them into the reactor, removing them, storing them, and processing them that makes the fluid-fuel system of the homogeneous concept so attractive. It must be pointed out, however, that industry frequently manages to get along with antiquated and cumbersome methods for a very long time. We now have a fuel-element-manufacturing industry well started. A number of large-scale reactors using such fuel elements are under construction. Some chemical processing plants will also come into being in the next ten years. Cumbersome as it may be, this whole process of solid fuel handling and processing may become a practical commercial enterprise. If this develops, the complexity of the solid fuel cycle, while still there, will become relatively harmless. The homogeneous reactor therefore faces the real challenge of bringing its fuel cycle to an equivalent state of use at an early date. It is expected that this will only happen if some large-scale homogeneous reactors are constructed and operated. If the homogeneous reactors wait for large-scale construction until the problems of the solid fuel cycle have been resolved, then it may be too late to attract the operators of power plants to the homogeneous type. The next ten years surely must see the construction of full-scale homogeneous power reactors.

7 Chemical Processing

The reactor designer now has a well-developed process for recovery of fuel materials from irradiated fuel and even has an "established" cost for this operation. The "established" cost is not so high as to cause concern. It is generally agreed that the solvent-extraction process is acceptable from the economic standpoint, at least where substantial quantities of irradiated material can be handled. Therefore, the further use of the solvent-extraction process for civilian nuclear power depends not so much on improvements in technology as upon existence of power reactors that will supply sufficient throughput to support a large size chemical processing plant. Just how this will be brought about in the U. S. is not yet clear. The probability is high that the federal government will furnish the first plant devoted to the processing of power reactor fuels.

An alternate way of handling the chemical processing is to integrate the processing with each reactor. This, of course, is the basic scheme of the homogeneous reactors, and large inventory charges have caused it to be proposed as the basic scheme for the fast-breeder reactor. In principle, the fuel material flows through the reactor continuously, is decontaminated, re-enriched, and reinserted into the reactor. This operation is a natural one for the homogeneous reactor. It is unnatural for the solid-fuel reactor, but is not necessarily excluded from being successful. Its first test in the solid fuel reactor will come about with the Argonne National Laboratory's EBR-2, and the first test of the integrated chemical processing will take place with the homogeneous reactor at Oak Ridge National Laboratory. If these schemes should succeed technically, then the adoption of integrated processing probably is a matter of capital investment. The next ten years ought to see a decision as to whether nuclear power will use central processing plants or whether integrated chemical processing associated with each reactor will prevail. It is most probable that solid-fuel reactors will use central processing; homogeneous reactors will use integrated processing.

The waste-disposal problem will not become a serious matter, and, indeed, we may anticipate that, both in the physical treatment of wastes and in their management, many improvements will be seen.

8 Oxide Fuel Elements

The present trend is strongly in the direction of constructing fuel elements of oxides of fertile and fissionable materials. The impetus for this development comes from the water-cooled reactors. It may be worthwhile to ask what is gained and what is given up in using the oxide fuel elements. The principal loss is connected with the lower density of the oxide material, which for some cases may pose a problem of operating reactivity. As a practical matter, reactivity is a crucial item only if an attempt is being made to operate the reactor on natural uranium. On the favorable side, there is the expectation of good radiation-damage resistance and compatibility with hot water. If one considers, however, that the next group of reactors to be developed will strive to free themselves from water as coolant, then the reasons for using oxide are not nearly so clear. For the sodium systems, metallic fuel elements can be used and still achieve temperatures which are a marked improvement over those obtainable with water. In the gas-cooled case, this is not as obvious since much larger temperature differences are involved and the melting point of the metallic elements is rather easily reached. It seems safe to predict that nonmetallic fuel elements will come into greater use. The extent of use in high-temperature applications will greatly depend upon the success achieved in obtaining a coating impervious to fission products. There is one point, however, which could become of considerable importance. Present techniques all seem to depend upon fabricating oxide pellets that are small cylinders. There are obvious advantages to having fuel elements of other shapes, such as flat plates. In applications where a high degree of the subdivision of the fuel is required, it may be that nonmetallic fuel will have difficulty in meeting the shape requirement. Perhaps the best observation that can be made about fuel-element technology is that the particular fuel element that will be preferred for many applications has yet to be developed.

9 Role of Heavy Water

Heavy water so far has failed to find a place in the civilian nuclear power picture. Its virtues as a moderator have been extolled many times and the AEC price of $28 per pound is a reasonably low one. For nuclear power generation, it would appear that heavy water could be used in three different types of reactors: It could be the moderator and coolant in a pressurized water reactor; it could be the moderator for a sodium-cooled reactor; it could be the moderator for a gas-cooled reactor. There is also the possibility that it could be the moderator and coolant in a boiling water reactor, but this is classed with the pressurized water reactor since the main problem, namely leakage of heavy water from the high pressure system, is the same. All of these systems, for reactors of adequate size, would operate on natural uranium. With the exception of the sodium-cooled reactor, either tank or tube-type construction is possible. In the next ten years, one or more of these reactors is certain to be developed in the United States, if for no other reason than to remain on a par with what is happening in European countries. The British Calder Hall reactor is the only existing example of a natural uranium power reactor. One of the heavy water types is certain to be developed as a strong competitor to the Calder Hall type. The pressurized heavy water reactor has the temperature limitation common to water reactors. In addition, pressurized heavy water raises the spectre of leakage losses which may be intolerable. The sodium-cooled reactor has the advantage of high temperature but, here, the problem is to make a convincing demonstration that a nuclear reactor containing highly reactive components, such as sodium and water, is acceptable from the safety point of view. The gas-cooled reactor has the advantage of high temperature, compatibility of materials, and a non-radioactive primary circuit, but suffers because of low heat transfer rates. Whether or not the heat transfer can be made sufficiently good to obtain power densities that will support an expensive moderator, such as heavy water, can only be determined by further design. As noted earlier, the various factors involved in the cost of power are interconnected in a complex way, and merely noting that heat transfer rates are modest does not necessarily exclude the reactor type from being economically successful.

10 Plutonium Recycling

The high buy-back price of plutonium that will exist until at least 1963 decreases considerably the interest in devising ways of recycling plutonium. This, of course, is true only in the U. S. In countries where enriched uranium does not exist and where there is not a market for high priced, low quality plutonium, the interest in plutonium recycle remains high. There is no doubt that practical schemes for the recycle of plutonium will be found. Some, indeed, are already in hand. The Canadian Chalk River Laboratory has found that it is quite feasible to make alloys of plutonium and aluminum, and that these can be fabricated into fuel elements. With widespread development and use of oxide materials for reactor fuel, the possibility exists of using mixtures of plutonium and uranium oxides or plutonium-thorium oxides for the construction of fuel elements. The situation with respect to alloying plutonium with uranium-238 metal or thorium metal is not so definite since obtaining satisfactory alloys may be quite difficult. If fertile material is not used as a diluent for the plutonium, the specific power of the fuel will be decreased, but this may not be a serious handicap. If the highly toxic part of fuel element fabrication, such as alloying with aluminum, can be confined to a single operation where adequate precautions can be taken, there is no reason why plutonium fuel elements should have a fabrication cost which is prohibitive. Plutonium recycle in the period ahead will first become a practical matter for those reactor types whose fuel elements are of the simplest construction. Pelleting oxides in an automatic machine, automatic casting of metallic slugs, or diluting in a large quantity of inert material and obtaining a protective surface by a simple plating process all are possibilities. But casting, rolling, jacketing, and welding as is done for some fuel element designs, if required to be done with highly alpha-radioactive material, does not promise low fuel cost.

Ten areas of power-reactor technology have been selected for comment. Even this short catalog poses enough problems to both inspire the research worker and to give good reason to believe that the hope for greatly improved machines, both technically and economically, is not a vain hope.

POWER REACTORS

4. outlook for utilities

By PHILIP SPORN

ELECTRIC UTILITIES have a three-fold responsibility: to the areas and people they serve; to the investors, that is the bond and stockholders; and to the employees who operate and manage the enterprise. It is the duty of management to plan, design, construct and operate its system so as to supply all the requirements of its service area for electric energy at the minimum cost consistent with safety and reliability and to provide with reasonable certainty for the continuance of such service well into the future. By virtue of that responsibility, progressive managements justifiably carry out programs of research and development in every sphere of their activity. Where such activities are carried out with skill and intelligence the over-all interest of everyone concerned is best served.

The utilities' current research should therefore include reasonable programs looking toward the eventual development of competitive systems of energy generation utilizing nuclear fuels. What should these programs be in the next decade? What will they be? Although related, these are different questions. From the standpoint of the utility alone, the first can be considered largely in terms of economics, lead times and other technical factors. The second, although involving these factors, can be dominated by such imponderables as prevailing public moods and public policies. In the main, I shall attempt to develop an answer to the first question.

Before that, a word about the outlook for nuclear power far in the future. For such a period we might picture the prospects with a broad brush. Looking ahead, say two decades and beyond, one sees the pressing economic forces that will increase the cost of conventional fuels as demand increases and supply becomes harder to obtain. During the same interval the cost of nuclear power, both capital and operating, should decline, possibly even sharply, as many of the difficult technological problems in reactor design, construction and operation are solved. In the long term, therefore, we would expect nuclear power to take its place side by side or, in many cases, to supersede more conventional methods of generation. Even in this statement of outlook, we must be mindful that in any long period many radically surprising things are likely to happen, contrary to our present expectations.

Whatever the long-term prospects, we already know too much about the present and the immediate future to permit dealing with the next decade in broad brush strokes. A decade represents a short period when one observes such factors as existing gaps in the crudely estimated nuclear power costs and the large gaps in experience and technical knowledge of large-scale power reactors. A decade is a brief time to fill gaps of these kinds. And to such factors there must be added another factor critically relevant in utility planning—the long lead time for any type of large power plant.

Today we cannot estimate with reliability nuclear costs prior to a commitment to proceed with a single project that might involve expenditures of $65,000,000 to $75,000,000 for a 200,000 kw plant.

There are actually three areas of cost, each with its own distinct problems: capital costs, fuel costs, and operating costs. The amount of reliable information now available in any of these three categories is very small in contrast to comparable data for conventional plants. Small reactors operating today do not give indices of capital costs for a large reactor designed and operated as a commercial enterprise. Shippingport, Dresden, Indian Point, Yankee Atomic, and Monroe, Michigan—to name the five largest reactors under way in the United States—are not yet ready to furnish reliable information on capital costs. Except for Shippingport, none will do so for several years to come. We do know that costs of nuclear projects have been rising steadily compared with earlier estimates and that the chances of bringing down costs to the utilities by contributions from manufacturers have also decreased to the vanishing point. Except for government aid, cost reduction can now be achieved only through solid technical advances.

The fuel cost problem is also difficult although perhaps not as difficult as the capital cost problem. Even here there is uncertainty and there seems to be no solid basis for judging costs extending over the expected life of a reactor except perhaps in the case of natural uranium. Fuel cost estimates in reactor operations involving frequently recurring hot chemical processing and significant but uncertain plutonium credits against original fuel cost are as yet too unreliable to provide a sound basis for a capital expenditure where estimated life may be from 20 to 30 years.

Operating costs are perhaps least difficult to appraise

although they are still not susceptible of the precise determination customary in conventional plants. Operating-cost factors weigh against atomic plants because of the more complicated codes of regulations, the complexity of carrying out certain work, particularly maintenance, and the need for more highly trained people.

For a long time to come operating costs of atomic power plants are going to be higher than those of conventional plants

On the basis of present costs, that is disregarding inflation, it seems reasonable to consider the typical case of conventional power as one in which the capacity can be constructed at a cost of $150 per kw. If we then make the entirely reasonable assumption of a thermal efficiency of 8,500 Btu/kwh in relatively large-size units of 200,000 kw or more, gross fixed charges of 14.5% and 80% annual use factor (7,000 hours' use of full capacity), you get the costs shown in the following table:

Item	*Costs (mills/kwh)*				
Fuel cost (¢/M Btu)	*15¢*	*20¢*	*30¢*	*40¢*	*50¢*
Fixed charges	3.11	3.11	3.11	3.11	3.11
Fuel	1.28	1.70	2.55	3.40	4.25
Operation & maintenance	.39	.39	.39	.39	.39
Total	4.78	5.20	6.05	6.90	7.75

The table shows that the economic target in conventional fuel costs for a nuclear plant to be completed in this country in the next ten years is a total cost roughly between 4.75 and 7.75 mills/kwh.

How close can an atomic plant visualized today meet this target? Here it is important to observe that it is impossible to try and develop today nuclear figures on either capital, fuel or operating costs that can stand up well enough to be compared with carefully prepared conventional power figures. The degrees of accuracy of knowledge of costs and, therefore, of the nuclear figures forming the counterpart of the conventional power cost figures are not of the same order. We simply have no solid basis for accurate nuclear cost projections. I need to point out, therefore, that the nuclear cost figures set down below have an element of tentativeness that makes them quite different from the high-degree-accuracy conventional power figures. And because of that I have erred purposely on the side of favoring nuclear plants in the costs given below.

In the above table 15¢ fuel represents about the lowest available in the U. S. today; 40¢ close to the highest; and 50¢ the probable highest that it will be necessary to confront in any important part of the U. S. during the next decade.

It will be assumed that the capital costs of a nuclear plant in unit sizes about the same as the conventional unit cited would be $325 per kw and the fixed charges, taking into account the higher depreciation of some components of plant but the lower carrying charges of certain items, are a total of 14%. The fuel cost, out of the large sets of figures that have been developed in the past year or two for heterogeneous reactors, will be taken at 2.00 mills/kwh. This figure could be taken as derived from a fuel cost of 18¢/M Btu and 11,000 Btu/kwh or 20¢/M Btu and 10,000 Btu/kwh. The components of nuclear energy cost, again at 7,000 hours' use of full capacity, then appear as follows:

Item	*Costs (mills/kwh)*
Fixed charges	6.50
Fuel costs	2.00
Operation and maintenance costs	1.25
Total	9.75 mills/kwh

The differences between the atomic and conventional are 4.97 mills, 4.55 mills, 3.70 mills, 2.85 mills and 2.00 mills for 15¢, 20¢, 30¢, 40¢ and 50¢ fuel, respectively.

If it is assumed, which seems reasonable, that this represents as good a reactor as can be put together for continuous operation commencing not later than 1966, then the annual cost burden as between a conventional and a nuclear plant—that is, the extra cost per year of operating a nuclear instead of a conventional plant—of 200,000 kw rating, generating a net of 1.4 billion kwh at 7,000 hours' use, becomes $6,960,000, $6,370,000, $5,180,000, $3,990,000 and $2,800,000 for 15¢, 20¢, 30¢, 40¢ and 50¢ per million Btu conventional fuel costs.

I have been discussing optimum costs that may be expected of a 200,000 kw nuclear power plant built for initial operation toward the end of the coming decade. That, of course, means plants on which initial construction would begin some years from now and which would take advantage of knowledge gained from research and development currently in process. This same 200,000 kw reactor, incidentally, probably cannot be undertaken in the light of today's more limited knowledge to be built for operation in 1960–61 to produce nuclear energy at a cost much less than 11.5–12.5 mills/kwh. If the mean of these two is taken, 12.0 mills/kwh, then the annual cost burden of a reactor built on today's technology, to operate late in 1960 or early in 1961, becomes $10,100,000, $9,500,000, $8,350,000, $7,150,000 and $5,950,000 for 15¢, 20¢, 30¢, 40¢ and 50¢ fuel, respectively.

From what has been said to this point, and pondering the very heavy annual burdens of operating large-scale plants will not soon prove economic. Taking into account economics alone, the next decade would not witness the completion of many large nuclear power plants in the U. S. A corollary conclusion is that a large amount of research could be supported by a single year's financial burden of operating a large-scale reactor.

There is another circumstance, apart from economics,

Philip Sporn

President, American Gas and Electric Co.; member of board of Nuclear Power Group, Inc., which is involved in Dresden nuclear power station.

that works against numerous large-scale power plants in the next decade. This circumstance is the rate at which the demand for electric service has been growing, the lead time required for completion of generation facilities between initial commitments and commercial operation, the necessity for adequacy and reliability of service.

Turbine and other large power equipment deliveries are now running approximately 30 months. Hence a good deal of the capacity that will be needed in 1959, and in some cases in 1960, has already been projected, construction has been started and commitments made so deeply that any change in plans is not practical. 1960 generating plants are therefore already largely tied to conventional fuel.

For the remainder of the decade, that is the years 1961 through 1966, we need to anticipate installations of from 70 million kw to 75 million kw of new capacity. I take this range from projections of requirements in this period that are now generally adopted. The question then is: What part of this generation should be nuclear? Considering economics alone, as we have seen, we should scarcely look to nuclear plants at all for power supply with initial operation in this span of years. In this connection, it is important not to overlook the fact that the improved nuclear plants that we expect to be built toward the end of the decade should be compared not only with a conventional fuel cost of 50¢ per million Btu in some important areas but, doubtless, with a continuously rising conventional fuel cost during the life of the atomic project. Even so, the annual cost burden, at least in the earlier years of operation of the nuclear station, is so great—as I have shown nearly $3,000,000 annually—that it is unlikely that the ascending curve of conventional fuel costs over the life of the plant can offset the burden.

Whether, apart from economics, technical considerations—especially reliability of service—would permit much of the total installation from 1961 to 1966 to be nuclear depends upon the outcome of research and development projects now in progress or yet to be started.

Meanwhile, utility management must determine what kind of a nuclear power program it should have in this decade. What kind of program will yield the cost data and the technical knowledge we need to arrive at a stage where we can plan large nuclear power installations with confidence as to cost and reliability of operation? More particularly, what kind of program will yield the maximum rate of progress in technological advance? Stated more specifically, our object is to reach in the minimum time that point at which the expected descending nuclear energy costs approach or equal conventional energy cost.

There is a considerable body of thought that believes that the best way to achieve the objective is to take bold action now and build at once a series of large-scale demonstration projects exemplifying a variety of reactor concepts. I think there is another approach to this problem that in the end may yield better results.

I do not disagree with those who urge that we shall never get the knowledge we need to project large nuclear plants with confidence as to cost and reliability until we build and operate large demonstration plants. This is the course that in my own company we naturally follow and that has recently given us gratifying results in a new approach to conventional steam stations. I am referring to our large demonstration project at Philo built in the period 1953 to 1957. The success of Philo has now led us to project our new supercritical steam pressure 450,000 kw units burning coal at Sporn and at Breed Plants.

But the important point is the research that preceded Philo. Here I believe then is an important lesson for those tackling the problem of building successful nuclear power plants:

Research on relevant problems and design, construction and operation of the smallest meaningful prototype should precede any attempt at full-scale demonstration

For myself, I believe that Lord Fisher's dictum—that experiment on the scale of 12 inches to the foot is not economical—applies equally well to the matter of time. The route I describe is, I believe, in the long run the quickest road to successful demonstration projects and a progeny of commercial reactors. I shall try to put this with greater particularity.

It is obvious from the evaluation of annual economic burdens imposed by the operation of a 200 Mw nuclear reactor, as given above, that what is needed is improved—indeed much improved—reactors. There is no dearth of ideas; the trouble is that none of the advanced ideas can be translated into practice until we first fill the big holes in present knowledge. To fill these gaps calls either for basic research, or research along a specific embodiment of a principle, or for engineering development, or for all of them.

The end sought is an advanced reactor, say of 200,000 kw output. But where the situation as to deficiency of basic or engineering knowledge exists, the obvious straight shortest path to the object is to remedy each of the difficulties in the shortest time, using the smallest scale of equipment consistent with the end sought and so also calling for a minimum draft upon the limited national pool of specialized manpower and manufacturing capacity. In my view the practical implementation of this approach is a program of research and development leading to the smallest useful prototype reactor, but all based on a preliminary projection of the full-scale 200,000 kw demonstration plant to be built as research, development, and operation each shows in turn the soundness of previous work and thus gives knowledge and assurance for the design and construction of the full-sized job.

Let me illustrate this point: A typical advanced reactor design to which we have given serious consideration embodies a number of well-known components put together in a new form. The essential elements are a ceramic fuel, a graphite moderator, and sodium cooling to produce steam at a temperature of around 1,000° F. These apparently simple elements if they are to be put together in a large-scale demonstration reactor still involve a research and development project of vast proportions.

Ceramic fuel has been known and worked upon for at least ten years. But much fundamental information about ceramic fuel such as detailed knowledge of thermal conductivity and of structural stability is lacking. Such fuel cannot be used without a large investigative program. Further, each reactor design, at least at this stage of development, generally involves a new fuel element

structure, of unproven feasibility and with the fabrication procedures unknown, so that actual production costs are impossible to estimate.

Graphite as a moderator has been used extensively but there remain many problems to solve before this material can be put together in specific shapes involving untried geometrics. When combined with sodium there are corrosion problems: If graphite should come in contact with the sodium it may act as a carburizing agent on some of the hardware such as the stainless steel piping. A remedy, involving the canning of the graphite, leads to other difficult problems of detection of leaks, for example, in the canning material.

Sodium as a coolant has been experimented with since the early days of power reactor development, but designing leak-free heat exchangers has yet to be really proved out. When the sodium coolant is used to generate steam, leaks present a major hazard since sodium and water are not compatible. While large sums of money have been spent thus far, and although progress has been made, it appears that, if future heat exchangers are not to be unduly complicated and therefore unduly expensive, a great deal more research and development on this problem need to be carried out.

Many other problems are raised by using sodium as a coolant. To mention just a few of them: There is the induced radioactivity in sodium and the problem of fuel handling when the fuel is brought out of the sodium coolant. The sodium technology with all its attractions still has a host of difficult problems to be solved before subjecting a large-scale reactor to its many pitfalls.

Analogues of the problems just described can be found in most, if not all, of the promising new reactor concepts. The fundamental research that may be involved should come as a prelude to any engineering or developmental work. From then on, proceeding along the small prototype route results in an important conservation of time, manpower, and materials.

Designing a large demonstration plant on short schedule becomes very expensive because of the necessary conservatism that in turn introduces inertia and delays

Changes, both engineering and construction, that are called for as a design moves along take longer on a large-scale project than on a small prototype and they require additional material and manpower. A dismantling operation after a partial or full operation period is longer and modifications are longer.

The lack of a prototype makes the problem of designing and successfully building a large unit much more difficult than going from prototype to demonstration size. Even when this is done there are plenty of pitfalls and uncertainties in extrapolation from a smaller to a larger size.

This is especially so when the extrapolation is beyond a modest ratio, say 1½ to 1 or 2 to 1, since the likelihood of encountering unknown limitations or unknown factors due to change in size beyond a modest limit is much greater. This has been the common experience in successfully developed new technologies and there is no reason to expect a different experience with the much more difficult technology of atomic power.

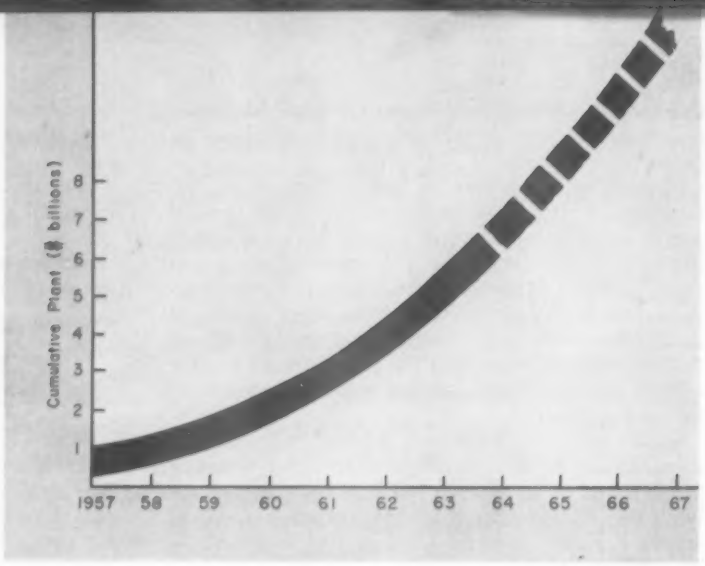
If the approach to developing competitive atomic power be via immediate, large-scale demonstration projects, then, with rare exceptions, expenditures beyond the capacity of industry alone are required. The two-stage approach, which I regard as preferable and which involves the smallest useful prototype followed by a demonstration plant, will be less costly. This will be even more so where the experience with the prototype furnishes insufficient basis for proceeding with the larger unit.

Development expenditures will be required of a magnitude that industry cannot manage by conventional means

Although many of the utilities of the country have been carrying out research and development in power technology over many decades, yet the fact remains that in the past a great deal of the basic research, particularly in equipment, although paid for by the utilities in the final result, was carried out indirectly by them through the manufacturers who treated the expense as a developmental expense to be added to the price of the equipment. That this procedure is not fully suitable in the case of atomic power has been recognized by the utility industry, which has organized regional and other groupings of electric companies to finance and carry out research and development directly. This is one of the most promising developments in the assurance of eventual competitive atomic power and of continuing American leadership in the field of power generation in the nuclear age to come.

The mechanism for the governmentally owned portion of the utility industry undertaking and carrying its corresponding responsibility in the 1956–1966 program of nuclear development has as yet not been clearly formulated. There is evidence of a tendency to project this along lines of completely AEC-owned reactor and steam producing installations on public power systems. There is grave doubt as to whether this is the optimum way of utilizing government funds to advance nuclear power technology and economics.

Government, and particularly federal government, aid can, in my opinion, be used more effectively and to better purpose. With so vast a program of research and development ahead government aid is justified, if for no other reason than the telescoping of the normal time to get results, as part of the "Atoms for Peace" program. But I believe that the best results will be obtained if such aid is concentrated along the lines described in this article. The substantial help that the atomic facilities and installations of the United States Government make possible in many ways would appear to offer an ideal way for bringing the Government into an effective developmental program. This help can and should include use of laboratory facilities, including material testing facilities, special arrangements for the use and processing of fuel, special arrangements for the use of heavy water, and the like. Where the erection of large demonstration units has reached the phase of maximum development made possible through research, experiment and prototype, then some form of government aid in sharing cost burden of the demonstration projects should be forthcoming. Government aid at the demonstration project stage should be made available in a form that will encourage the widest interest in participation by all segments of the economy, private or public alike.



CUMULATIVE EXPENDITURES on nuclear reactors and related equipment and facilities (based on and extrapolated from Forum survey, April, 1955, by NUCLEONICS)

POWER REACTORS

5. equipment market

By ALFRED IDDLES

THE NEXT DECADE promises to be one of steady, solid and substantial growth for nuclear power equipment manufacturers.

However, three factors are presently acting as a brake upon the rapid growth of this market—the time required to train necessary personnel, the time needed to construct the first prototype plants, and the projected costs of these first plants. Furthermore, growth is limited to the rate at which management, engineers, shop superintendents and foremen can be adequately trained in the new atomic art.

The electric power generating industry will undergo its greatest expansion during the next decade. It can also be predicted with some degree of confidence that the growth of the nuclear manufacturing industry during this ten year period will account for an increasing proportion of this central station business. Here are some events that may occur in the nuclear field during 1957–1967 set forth with the possible impact on nuclear fuel and equipment manufacturers:

The next ten years may see the development and demonstration in this country of several promising reactor types—aqueous homogeneous and liquid metal fuel systems, reactors cooled with gases, and reactors moderated with organic fluids or heavy water. Reactor manufacturers are intensely interested in all of these and other advanced designs. Some manufacturers are investor-participants to the extent of having allocated large amounts of money and manpower for these projects.

Impact of these advanced designs upon the reactor equipment manufacturers, insofar as numerous installations are concerned, is likely to be felt several years beyond the time schedule of this survey, probably between 1967 and 1972. Much research and development must be conducted on these reactors before they reach the state of technology of the water-type reactors.

Of particular significance to reactor manufacturers is the Navy's decision to concentrate on the pressurized-water reactor based on the Nautilus' demonstration of inherent safety and practicability. Electric utilities both in the U. S. and abroad have also expressed confidence in the pressurized-water and the boiling-water types by proceeding with the construction of more than a dozen of these.

It is still rather early to predict which of the many reactor concepts will ultimately be capable of generating the least expensive electrical energy. It seems not too unreasonable that more than one will gain acceptance throughout the world, the local economic and geographical conditions being the determining factors.

The AEC is committed to buy U. S. uranium ores at differing prices through 1962. Additionally, the AEC is also buying uranium from Canada, the Belgian Congo, and South Africa. During the first half of the forthcoming decade the AEC will continue to have domestic uranium milled in privately-owned plants. Between 1962 and 1967 the AEC has obligated itself to purchase some U_3O_8 concentrate from U. S. producers at a price of $8/lb.

Until 1962, the AEC will probably continue operating government-owned refining and purification facilities. However, a new contract for the refining of 5,000 tons of uranium/yr in privately owned facilities will also be in effect soon.

Between 1957 and 1967 it is possible that the AEC may choose to curtail somewhat the purchases, milling and refining of uranium feed material for military purposes because of a diminishing uranium need for weapons purposes or because of international agreements. By 1967 the uranium needs for nuclear power will not require the full capacity of our present government- and privately-owned supply and facilities. It is believed that the capacity of the gaseous diffusion enrichment plants, in particular, is more than adequate for our foreseeable nuclear power needs during 1957–1967.

During this decade other governments desiring to purchase uranium may enter into private arrangements with mining concerns in the U. S. (under license) or with Canada or other governments for guaranteed long-term deliveries of natural uranium. Prices for uranium from these sources may tend to be lower than the present values, especially if AEC's weapons procurement is drastically curtailed during 1957–67.

Governments, utilities, and manufacturers in foreign countries, in order to save dollar currency, may seek to make arrangements permitting them to send to the U. S. natural uranium which they may own or may be able to purchase in softer currencies. Here it would be enriched at existing AEC diffusion plants. Some countries may also find it expedient to trade native supplies of thorium or natural uranium for enriched uranium from the U. S.

Also, for various reasons, new uranium, milling and refining facilities may be constructed abroad during 1957–1967, but there will be less economic incentive to build such new U. S. facilities.

In any case, adequate supplies of fissionable material can now be made available by the U. S. for both domestic and foreign nuclear power plants. The U. S. has made available 100,000 kg of uranium currently valued at about $1,700-billion and we may be certain that the U. S. will make available additional quantities of fissionable materials to both domestic and foreign reactor owners in keeping with its pledge to support the worldwide "Atoms for Peace" program. Moreover, the supply of enriched uranium should not be considered a "limiting" factor to the worldwide growth of nuclear power.

Within the next decade zirconium manufacturers may achieve quantity, low-cost production of zirconium ingot, sheet and tubing.

One of the important raw materials for fuel element manufacture is zirconium. Zirconium sponge producers have already accomplished high-volume production at reasonably low prices under AEC contract, and this high volume should continue.

The Navy has contracted for 2-million lb of zirconium per year for its over-all program, including PWR cores, at prices ranging from $4.53/lb to $11.42/lb.*

Several privately-owned facilities for the fabrication of enriched-uranium fuels have already been built and are now in production. We can expect to see more facilities of this type in operation by 1967. Currently, these fuel element manufacturing facilities are primarily used to produce fuel elements for naval propulsion reactors and for research, engineering and test reactors. During 1958–59 the production of these plants will be partially redirected toward the fabrication of core loadings for the first large-sized nuclear power plants.

Costs for second and third core loadings will be lower between 1962–67 as manufacturing process changes from developmental to full-scale production

Very likely the Navy's requirements for fuel elements will also be substantially increased during this period. [In testifying* before Congress, Admiral H. G. Rickover reported at the present rate of nuclear shipbuilding the Navy would have about 1½ million kw of nuclear capacity in ships by 1963 and that the ships under construction would account for an additional one million kw. As far as fuel is concerned, this means, according to Rickover, that in 1958, the Navy will "have about $50-million worth of reactor core business alone . . . (and) once you get a ship in the water with a core you have got it there three or four years, then you have to take the core out and put a new one in."]

Some of the enriched uranium fuel fabricated by U. S. plants will be installed in the reactors scheduled to be built in the Euratom area and in other countries. As the installation of nuclear power gains momentum in Europe facilities for the manufacture of enriched fuel elements

* Naval reactor program and Shippingport project. Hearings before subcommittees of Joint Committee on Atomic Energy (Congress of the U. S., 85th Cong., 1st Sess.) March 7, 1957, p. 14, 86.

Alfred Iddles

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may be built on the continent. Some U. S. manufacturers may build fuel-element plants abroad, while others may make arrangements with continental manufacturers to produce enriched uranium fuel elements under license.

During the period between 1957 and 1967, the fabricators of nuclear fuel may be called upon to incorporate plutonium and uranium-233 in reactor fuels. During this time significant quantities of Pu, and a smaller amount of U^{233}, will have been produced in the irradiated cores of several full-sized reactor power plants. The first Pu and U^{233} would probably be utilized for large-scale experimental purposes to develop the techniques of fabrication into useful reactor fuels.

Successful fabrication and demonstration of the use of Pu and U-233 may lead to the establishment of supply-and-demand values for new fissionable materials

Pressure vessels for pressurized-water and boiling-water type reactors will continue to be built at an increasingly rapid rate, mostly for the naval program. The Navy will expand its nuclear program from the current submarine and aircraft carrier projects to include practically all new construction. This decade will witness the completion of the nation's first nuclear-propelled merchant ship, an event that will probably stimulate the construction of additional nuclear-propelled tankers and cargo vessels. At the end of the decade a great many of the world's supertankers could well be nuclear-propelled.

Pressure vessels for the first full-scale power stations will be fabricated in the shops by 1958–59 and should be followed by additional reactor pressure vessels for the second and third round stations a short while later. Some pressure vessels may be fabricated in the U. S. for installation in Europe, Japan and other areas.

New manufacturing plants need not be built since facilities and production techniques are similar to those already used in manufacturing conventional boiler steam drums and heavy pressure equipment. Present facilities, if expanded, are well suited for fabricating this heavy nuclear equipment.

Pressure vessels for reactors are now limited in internal pressure to a steel thickness of approximately 8 in., the maximum steel plate thickness which can be economically obtained today free from internal defects. During 1957–1967 the steel manufacturers may be able to increase this limiting dimension. Design ingenuity and vessel closure tests may lead to the manufacture of larger pressure vessel head openings, leak-proof gasketing, and the avoidance of seal welds.

Control rod drives attached to these pressure vessels may become more standardized, and this may aid in achieving lower capital costs. Nuclear reactors requiring fewer control drives may be developed before the end of the coming decade.

Production of high capacity pumps for pressurized water reactor primary systems will be substantially increased between 1957–1967, as will the manufacture of large stainless steel gate valves and check valves.

The stainless steel heat exchangers used with pressurized-water and boiling water reactor systems are quite similar to equipment currently manufactured for the chemical industry. The steam drums and their internal cyclone and plate-type steam separators are essentially identical with conventional boiler equipment. It is indeed fortunate that manufacturers now possess the technology and the necessary facilities for the speedy fabrication of these pumps, valves, and steam generators.

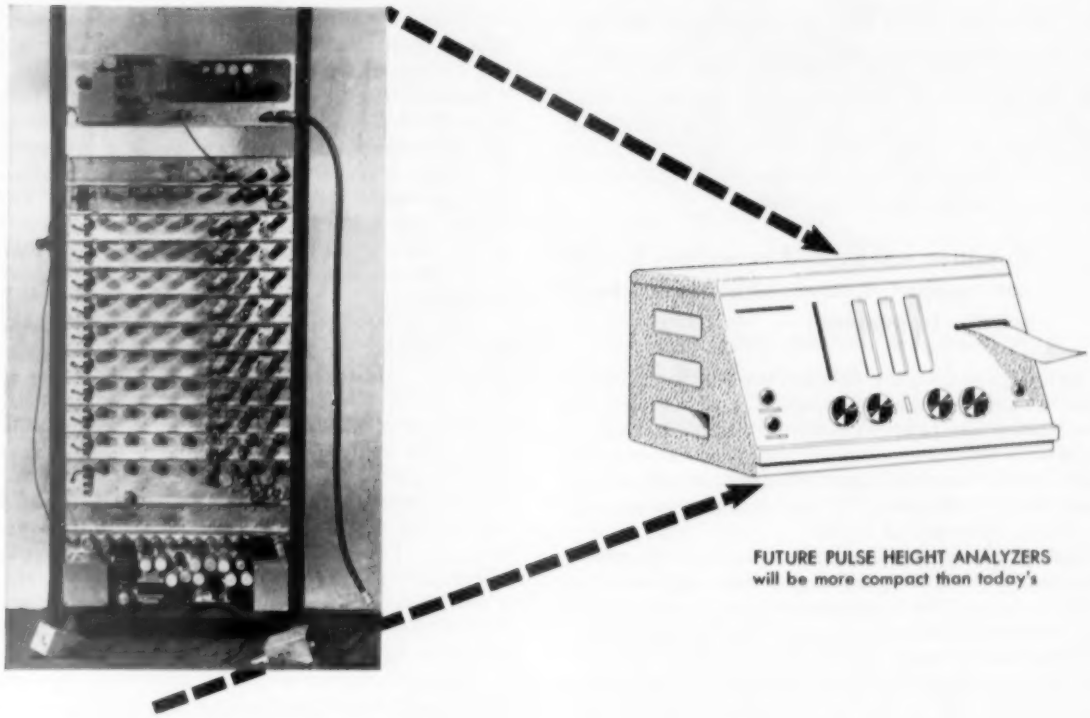
The outlook for nuclear equipment manufacturers points to a continually increasing production of naval and central-station reactor components. Many reactors are now being constructed by industry and under the AEC power demonstration program to test feasibility and to obtain operating data.

Tempering the economic optimism noted prior to 1957 is the realistic reappraisal of costs for containment, shielding, and waste disposal systems for nuclear plants now under construction. Electric utilities are stressing hazard prevention. Desire for immediate and continuous trouble-free operation of early plants has introduced extra cost and contingency into the previously proposed designs, resulting in higher capital costs for nuclear power projects. There is reason to believe that this design trend will be reversed after the demonstration of the first full-scale stations, and that the many new nuclear plants which will be contracted for by 1967—many in the high cost areas of the Northeastern states, in Florida, and on the West Coast—will be economically competitive.

Coal is expensive in Western Europe and Japan, and the cost of its extraction has risen with steadily depleting reserves. These areas, traditionally dependent upon coal, have resorted to fuel imports at alarmingly high rates causing considerable economic problems. In their report, "A Target for Euratom," the Three Wise Men wrote "European energy imports would rise to intolerable heights without nuclear power . . . already the six countries import nearly one-fourth of their energy supplies . . . most of which is oil from the Middle East. The Suez crisis has shown how precarious these supplies are." To stabilize their oil imports at the 1962 level, which according to Franz Etzel, Vice President of the European Community for Coal and Steel, will be approximately 30% of Europe's total energy requirements, the Euratom countries must commission by 1967 nuclear power plants with an installed capacity of 15 million kw.

One-half of the Euratom countries' projected nuclear installations, say 7 million kw, may be based upon U. S. technology. This will provide a new market for the U. S. nuclear equipment manufacturers for those fuels and components that cannot be manufactured on the continent in a timely manner or in sufficient quantity. Although some member nations consider this to be an ambitious program, it can be reasonably assumed that at least one-half of this target will be realized. Enriched uranium reactors appear to be economically attractive in the Euratom countries today.

Meanwhile, U. S. nuclear equipment manufacturers will draw on their reservoirs of skilled manpower, experienced engineers, shop supervisors, sales representatives, field construction and service foremen by training and educating them in the nuclear art. This, of course, cannot be accomplished overnight, but by concentrating efforts, the power equipment manufacturing industry will undergo a greater rate of expansion of effort than it has ever experienced in any previous period of its growth.



FUTURE PULSE HEIGHT ANALYZERS
will be more compact than today's

nuclear instrumentation

By DENIS TAYLOR

THE MANUFACTURE OF nuclear instrumentation is today a thriving industry, which, like NUCLEONICS, is celebrating its first ten years of existence. Their product is an ever-increasing variety of nuclear measuring instruments at highly competitive prices.

Before looking forward to the future and considering the problems, trends, and prospects in the field, it is worthwhile looking backward and deciding what, precisely, has been achieved in this last ten years. Initially we had a very few organizations manufacturing and marketing nuclear measuring instruments. The instruments required by our nuclear physicists and radiochemists for development work and research had to be designed and hand made in the laboratory. A few experts had the good fortune to have a background of experience in electronic techniques and sufficient knowledge of experimental nuclear physics to understand what was required.

All this has now changed. The experts are still there, but there are many more of them. They are found not only in our national laboratories but also in the design offices of our nuclear-instrument industry.

Whereas a few years ago the nuclear instruments being marketed were all, or almost all, based on designs originating in the national laboratories, the situation now is that a high proportion of the instruments on the market have resulted directly from private enterprise by the manufacturer.

The industry is, in fact, standing very firmly on its feet

Today we face the challenge to improve present instruments; in the years ahead we will meet problems that cannot be solved with existing instrumentation.

New components. Nuclear instruments are now appearing using the new components, e.g., the transistor and

the ferrite loop. Both have important advantages and serious limitations, but used intelligently, they can help designers to produce more satisfactory instruments. The advantages outweigh the limitations in the case of small portable instruments, because of the transistor's small size, low power consumption, and good reliability. This is also true in the case of the more elaborate nuclear instruments employing digital-computer techniques.

Transistors will be used increasingly but will not supplant vacuum tubes; ferrite loops will also be popular

In a large number of other cases transistors can only be used by accepting some deterioration in performance. In some cases, therefore, thermionic tubes must continue to be used in spite of foregoing the possible reduction in size and power consumption, and—often more important—improvement in reliability. In some cases at least this may be a temporary state of affairs.

Thus designers at the present time prefer to employ thermionic tubes for pulse-amplitude-to-time-conversion circuits, because the temperature-sensitive transistor leakage current would make it very difficult to store pulse amplitudes accurately for the necessary time. Also, no simple way has been devised so far (again because of the high leakage current even with a silicon transistor) of measuring the small outputs ($\sim 10^{-12}$ amp) from ionization chambers. Hence electrometer tubes are still used for this purpose. In this case, however, there is probably very little incentive to use transistors, as electrometer tubes are relatively inexpensive, small in size, and more reliable than the majority of other thermionic tubes. The power consumption and voltage required can be very low.

Other new components are likely to find increasing application. This applies particularly to the ferrite loop, which is beginning to be used in scaling circuits, storage systems, etc., in the more complex nuclear instruments. This will obviously continue on an increasing scale as will the use of the new production techniques, encapsulation, printed wiring, expendable subassemblies, etc.

It is of interest to note that printed wiring is being used at the present time in a number of nuclear instruments, for which only a small number are required, not only on the basis of allowing higher reliability, more compact design, etc., but also on the basis of its lower cost.

Denis Taylor

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Scalers. During the last ten years the ordinary scaler has suffered several revolutions in design. In the early days a number of scales-of-two in cascade to give scales of 2^n were used, scales of 32 and 64 being popular. Later everyone wanted scales-of-ten, which involved a $2^3 + 2$ or similar system. Whilst it was more convenient from the point of view of the user, it was also more expensive and more elaborate and therefore less reliable than its earlier competitors.

Later still, decade counting tubes providing a scale-of-ten in one envelope were introduced, allowing some simplification in the design of the complete scaler and some improvement in reliability. Decade counting tubes are self-indicating, which is a real advantage, and a number of versions of them are now available for operation at different speeds.

Fast switching. Now the transistor and the ferrite loop can be used in place of the thermionic tube as switching elements. For the standard scaler with a resolving time of 2–5 μsec and a scale of 10^5 (or a scale of 10^3 followed by a mechanical register) all the switching components can be used: thermionic tube, decade counting tube, transistor, and ferrite loop.

Scaling circuits can be evolved using the newer components, which are extremely economical in power supplies. Ferrite loops in a ring circuit with transistor drive look an extremely attractive proposition, and now that Franklin and James have devised a compact and robust magnetic indicator that can be part of the ring circuit and not really add to the power-supply problem, it seems very likely that this, at least, will be one of the popular scalers in the next few years (*1*).

Fast prescalers. Apart from the standard scaler, specialized nuclear physics experiments have brought a need for a fast prescaler with a resolving time of about 0.1 μsec. Thermionic tubes have been used so far for this purpose. However, by taking advantage of the superior mutual conductance of the transistor, it is easier to make a fast prescaler using transistors than by using conventional tubes, and it is fairly certain that fast prescalers using transistors will soon make their appearance. Furthermore, if, in the future, it is necessary to have scalers operating at speeds in excess of 10 Mc/sec, the transistor is still a component to be considered.

Nuclear physics research. Looking still further ahead, it is evident that much special equipment will be needed in the future for nuclear-physics research. With the high intensities possible with the newer types of pulsed accelerators coming into commission and with the chance coincidence rate very high, it will be necessary to use apparatus with extremely short resolving times. Experiments are being proposed, for example, needing coincidence-resolving times of a few millimicroseconds, and it may be necessary in certain instances to provide counting equipment capable of operating at speeds of the order of 100 Mc/sec.

High-speed counting. Attempts to provide very-high-speed counting equipment have been based on the original Eccles-Jordan scale-of-two, but although the system worked at about 40 Mc/sec, it proved extremely elaborate even for one binary scale. Many now consider that the

only satisfactory solution will be to use diffused-base surface-barrier transistors. It will be interesting to see what the future holds.

At the present time improvement is probably needed most in the radiation detector. Resolving times of the order of 5–7 μsec are possible with a scintillation counter, but electronic circuits can more than match this figure. Some improvement can be obtained by using selected photomultipliers and using only a small portion of the cathode. But it would be very satisfactory if an improvement of, say, a factor of ten were obtained.

Kicksorters. What are the trends in the more complex nuclear physics instruments? In the case of pulse-height analyzers, the minimum requirement is for 60 channels with no overlap and no gaps between channels so that every pulse is counted once and once only. Channel widths must be equal and constant to an accuracy better than 1%, and linearity must be better than 1%. An analog display seems to be essential in many cases, but readout facilities in digital form are required, and a great deal of attention is now being given to recording the information so that it can be properly analyzed.

At present, pulse-height analyzers are large and cumbersome equipments. With the new techniques it should be possible to produce a small bench analyzer that will serve for general work.

The next step will be simultaneous analysis in both pulse height and time

An apparatus, combining the functions of the pulse-height analyzer and the time-of-flight spectrometer could yield, for example, the energy distribution for a particle of a given mass. Essentially this will mean having a three-dimensional store and facilities for extracting particular information as required. At present this probably seems a gigantic proposition, but there is a real requirement for it, and with miniaturization techniques and the use of highly reliable components it will come. It is interesting that such elaborate units imply equally elaborate self-test facilities.

Reactor instrumentation. The instrumentation of power reactors has proceeded so far on the basis that these plants are still experimental. In the future it will be necessary to determine more precisely what is really required for proper operation and safety of the plant and provide this only. It will also be necessary to simplify the instrumentation and make it less cumbersome.

Reactor instrumentation will be simpler and include only that essential for operation

For example, the need to use a number of flux-measuring channels to cover the complete range of power level from shutdown to full power is a complication that it would be desirable to avoid. Some simplification has resulted from the use of artificial neutron sources, but a completely satisfactory solution is still awaited.

The quantity of interest is the fission rate, and this is determined at present by measuring the neutron flux (*2*). It would be much more satisfactory if the fission rate could be measured directly, but a method that can be used for reactor control is still awaited.

There are still a great many minor things that would be worth doing. Some of these are miniaturization of reactor instruments, improvement of the reliability of reactor instruments by the use of long-life components (e.g. transistors in shutdown amplifiers), redesign of neutron-sensitive detectors for higher temperatures, etc.

Finally what about future reactors and, in particular, the fusion reactor? In some cases special instrumentation is required, but so far the nuclear instrumentation does not appear to present fundamentally new problems.

Whole-body counters will become an important health-physics tool

Health instruments are in a special category because in many cases they are already relatively simple and are, or can be, very reliable. Undoubtedly there are a number of special problems that have not been satisfactorily solved—For example

- The monitoring of particulate activity in the atmosphere and the monitoring of fast neutrons at low levels in the presence of high gamma-ray fluxes.
- The measurement of whole-body radiation to determine the presence of any inhaled, ingested, or absorbed activity and to identify the material. This appears to be a very powerful method since it can potentially be used in the case of beta emitters (e.g., Sr^{90}) by measuring the bremsstrahlung and in the case of an alpha emitter like Pu^{239} (because of the low-energy X-radiations it emits) as well as with gamma emitters. The further exploitation of this technique is very necessary.

Reliability is a subject that has been to the fore for a considerable time, but much still remains to be done. It is a fact that few nuclear measuring instruments give the trouble-free service required (*3*). For example, my broadcast receiver at home has been in use, on and off, for the last seven years. Only one fault has occurred in this time. Someone tripped over the cord and broke it. Until nuclear measuring instruments can give something approaching this sort of service more work is indicated.

The instruments of the future will be more reliable, yet do more data processing

Another complaint that can be made by the more enlightened user is that today's instruments are not designed to give him automatically the quantity of interest; instead, they often indicate some related quantity. Thus scalers give the answer normally as a number of counts. However, the experimenter is almost always interested in the counting rate rather than the counts in a particular period. Why not, therefore, design the instrument to indicate the particular quantity of direct interest (*4*)? This is a definite trend that is both worthwhile and worth noting.

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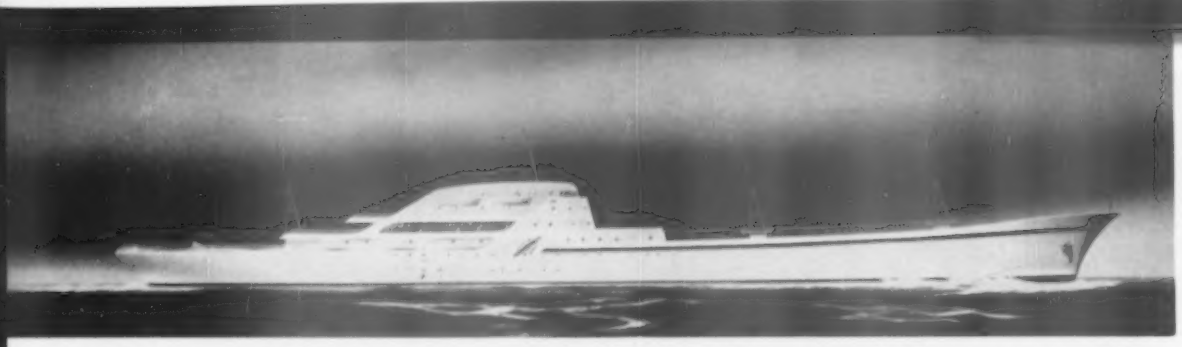

Artist's conception of first U. S. nuclear-powered merchantship. 11,650-displacement-ton, 20,000-shp vessel will be 588 ft long, 78 ft in beam, carry 60 or more passengers, 130 crew and 9,340 tons cargo at 21 knots

ship propulsion

By RICHARD P. GODWIN

When Congress authorized construction of the first nuclear-powered merchant ship, there was little doubt that it was technically feasible. The question was whether nuclear propulsion for merchant ships was *commercially* feasible.

In the summer of 1956, the Maritime Administration and the Atomic Energy Commission initiated a program to carry forward the construction of the first ship and also to conduct a series of engineering studies to probe the possibilities of commercial nuclear propulsion. Sufficient time has not elapsed for results of these inquiries to have been altogether conclusive; however, work that has been done has in no way lessened the anticipated promise of commercial nuclear propulsion.

In attempting to forecast trends in the next decade, it is important to understand the complex political, technical, and—most important—economic factors that have motivated the maritime industry from the time of earliest sea commerce. It is also necessary to understand the present position of U. S. flag vessels in world commerce to determine whether nuclear propulsion is a possible solution to its present weak competitive position.

All through historic times, the trend in water commerce has been towards vessels of higher speeds and increased cargo capacity. During each age, ship operators have employed the cheapest source of propulsive power available: manpower, then sail, fossil fuels, and now possibly nuclear energy. The transition from one to the next was gradual and usually passed through a period where two competing power sources were employed together. Each in its infancy was usually not competitive with its more highly-developed predecessor; and in most instances the change-over was pioneered by the military.

As civilizations spread, commerce expanded. Ocean commerce is still expanding at an amazing rate. For instance, in the period 1946–1956, total water-borne trade to and from the U. S. alone increased from 122- to 226-million long tons. It is to be expected that this upward trend will continue for many more years.

Up to the time when fossil fuels replaced wind and sail, it was axiomatic that more ship speed meant more ship earnings. Today, earnings are also dependent upon payload, trips per year, and other costs of operation such as shore facilities, maintenance, canal and port usage changes. At first glance it would appear to be a simple matter to increase ships' speeds, thereby increasing the number of trips per year. Unfortunately, it turns out that at higher surface speeds, power costs rise more sharply than revenues.

Few commercial ships built over the last ten years would have speeds in excess of 16–18 knots if economic considerations alone were governing. To raise the speed of a merchant ship by, say, 1% over 20 knots requires about a 6% increase in the built-in power per ton of ship weight.

This is aggravated by the fact that it does not appear possible to reduce appreciably the weight of conventional boiler systems. Further, we have leveled off at steam conditions of about 600–850 psia and 850°–900° F, and at the moment there is no compelling reason for change.

Certain technical and economic aspects of conventional propulsion plants have resulted in the use of three principal types. Large vessels with power requirements in excess of 9,000 shaft horsepower (shp) employ the geared steam turbine; 6,000–8,000 shp vessels tend to diesel power, while gas turbines are becoming increasingly popular in the lower power ranges. This is significant since, in all probability, no one reactor type will be best suited for all nuclear ships.

Rather, several reactor types are likely to be employed, each optimized in a particular power range

As is well known, the U. S. merchant marine has become heavily dependent upon operating and construction subsidies because the high living standards of American shipyard workers and crews result in wages 2–3 times those of their foreign counterparts.

These higher U. S. operating and construction costs re-

TABLE I—Tanker Power Plant Weight*

	1960		1967	
	Conventional	*Nuclear*	*Conventional*	*Nuclear*
Conventional machinery, wet	770	935	750	648
Oil-fired boiler & auxiliaries	240	—	240	—
Reactor system & auxiliaries	—	500	—	400
Shielding & containment	—	1,420	—	1,160
Nuclear plant structure	—	65	—	50
Plant total weight	1,010	2,920	990	2,258
Pounds/shp*	111	321	109	250
Diesel oil	9	227	9	—
Fuel oil (98% full)	3,830	60	3,800	—
Total fuel oil weight	3,839	287	3,809	0
Total weight	4,849	3,207	4,799	2,258

* Weights in long tons for 20,000-shp tanker.

sulted in U. S. ships carrying only 21% of the 226-million tons of cargo carried to and from the U. S. in 1956. U. S. ships carried only 14% of the dry cargo carried in the tramp field and are losing ground each year. Only in high-speed liners did the U. S. carry more than 40% of our exports.

By 1965, 85% of the U. S. dry cargo fleet will be nearing obsolescence. To maintain our merchant marine at a level consistent with mobilization requirements could result in an annual Government outlay of 150–200-million dollars for construction subsidies plus an annual outlay to private operators of 140 million (at present levels, before recapture of Government share of profits) in operating-cost differential subsidies. Since our Government participates directly in the profits earned by so-called subsidized lines (this is probably the only Federal subsidy with the recapture feature built-in), it stands to reason that the Government also has a stake in the goal of producing merchant ships with increased earning capacity.

In passing the law to build a nuclear merchant ship to operate in foreign commerce, Congress did not specify the vessel type nor the date the vessel was to be launched, but made it clear that the ship was to pioneer the way to commercial adoption of nuclear propulsion. While *Nautilus* had demonstrated technical feasibility, it was recognized that this did not automatically assure commercial success of nuclear propulsion.

Certain features incorporated in the first A-ship's design were necessary in the interest of saving time; others the result of a possibly over-conservative approach. Several of these features, while possibly obvious, are worth considering.

1. There are a number of possible ways—from a ship-design standpoint—that radioactive materials can be contained in the event of a reactor incident. Probably none are better than use of a separate containment vessel of sufficient size and strength to contain the maximum credible accident. At the present time, with limited experience, it does not seem prudent to approach commercial shipboard reactors in any other way. The necessity for operating the reactor in populated harbor areas, as well as for the general safety of passengers and crew, appear to justify at this time the added weight and costs associated with this approach. With operating experience, use of a separate containment vessel can possibly be eliminated in later ships and the ship's structure relied upon.

2. The location of the reactor plant for the first ship is essentially at the center of buoyancy. This was dictated primarily by the need for flexibility with respect to reactor shielding. Since the total weight of the reactor shield was not known and would be dependent upon crew and passenger tolerance levels, it was wisest to accept a location relatively insensitive to major weight changes.

3. Reactor location dictates to a major extent the location of superstructure. In the case of the first ship, the superstructure will be just aft of amidship to minimize shielding weights and avoid the need of providing access to the reactor compartment through the superstructure.

4. The secondary shielding will utilize shadow shielding (shielding of individual components on the side to be protected only) to the extent practical and up to the point where maintenance becomes difficult. It is also quite probable that the use of segmented lead shielding may result in substantial weight savings.

The first commercial ship may set the style for the immediate future.

It is hoped that we can progress rapidly to more functional designs that can be engineered from the keel up for commercial nuclear propulsion

Having considered some features of the first ship, it is interesting to look even further ahead and speculate about characteristics of the commercial nuclear-powered vessel of the future.

Appearance. Generally speaking, ship types and hull

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forms are married to particular trade routes, cargoes and speeds. Basically, present-day vessel designs can accept nuclear plants with few necessary structural changes. This will probably be the case for another six years or at least until the effects of increased speeds and more rapid cargo handling facilities dictate modification. In the meantime, structural changes will probably be limited to removing stacks and shifting superstructure forward or aft of the reactor plant. To employ nuclear power best, full advantage must be taken of all available ship spaces including inner bottom, uptake spaces, and volume available as a result of smaller power plants. As speeds increase, some streamlining or lowering of the superstructure could be justified. How far these visual changes will go is pure speculation at present.

Speeds. Until the time when nuclear power costs come to equal or drop below fossil fuel costs, it is unlikely that nuclear-ship operators will strive for speeds much over 20 knots. Ship speeds optimized for present-day conditions will probably remain constant through most of the next decade. Toward the end of this period, a definite upward turn will take place as a result of decrease in weight and costs of nuclear power plants, together with decreasing fuel cost. Results of a vigorous development program to improve turn-around time of ships in port will begin to be felt. For example, stern or side modular loading techniques, together with prepackaged cargoes, will be adopted, reducing lost time in port.

There will be a practical upper limit to surface ship speeds and as at present it will be governed by economic considerations. Since the very nature of water surface transportation makes it a losing game to attempt speeds much in excess of 35 knots employing fossil fuels (because drag increases as the cube of the speed), it is doubtful whether nuclear power could alter the economic factors sufficiently to attempt speeds much higher.

Between 1960 and 1965, 5–10 experimental or first-generation nuclear-powered merchant vessels will be built or building

Propulsion plant. The coming decade will see a significant shift toward nuclear ship construction. Probably these vessels will employ relatively well-understood reactor types, including the pressurized water, boiling water and possibly the organic moderated reactor. The organic system at the moment is speculative; a better understanding will be possible after experience operating AEC's Organic Moderated Reactor Experiment.

The light-water boiling reactor and the organic moderated reactor with lower pressures and possibly simplified auxiliary equipment may offer an early avenue to reduced capital costs. This is not to imply that the pressurized water system cannot lower costs and improve performance, as this seems quite probable. Fuel costs for these three systems seem to be about equal at the present stage of development. Costs for all three will certainly drop in the next decade.

The gas-cooled reactor closed-cycle turbine system, while not yet at a point where a realistic appraisal can be made, could reach a hull by 1965 if it lives up to its early promise. The gas system is of longer-range interest, and thus one should approach its development cautiously, recognizing the many technical problems requiring solution prior to utilization. The need for good high-temperature fuel elements, seals, valves and adequate emergency cooling methods and control system all dictate a cautious approach.

Ideally, high fuel burnup—preferably in excess of 3,000 Mwd/ton—and a relatively high conversion ratio would lower fuel costs. These factors in themselves, however, will not make possible economic propulsion. Rather, high burnup and conversion ratios must be equated against over-all costs and therefore something less would be acceptable. Ingenuity in design of practical propulsion plants must include simplicity with respect to maintenance and reliability with respect to performance.

It is much too early to forecast future merit ratings for each of the aforementioned reactors, or indeed to predict the value of other concepts. Suffice it to say a single system will probably not be proven best, certainly not over the wide power range employed in merchant ships—1,000–50,000 shp.

The major factors governing acceptability for propulsion purposes through 1967 will be:

1. Plant must have a high degree of inherent safety sufficiently contained to permit operation in populated harbor areas.

2. Plant costs should approach $400/shp in the 20,000-shp range.

3. Weight of installed reactor plant and propulsion machinery including containment and shielding should

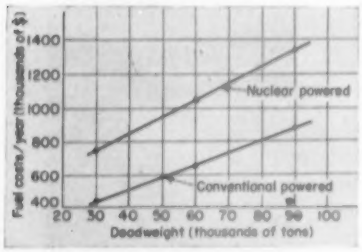


FIG. 2. Nuclear vs conventional fuel costs on annual basis for tankers to Persian Gulf. AEC-MA group thinks two lines will actually converge, not diverge, with nuclear power being relatively less costly per unit in larger applications

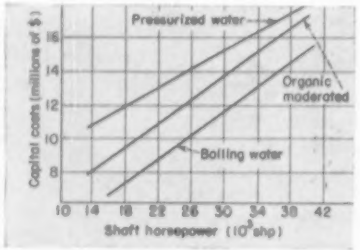


FIG. 3. Capital cost estimates. Top line based on B&W studies for first A-ship is penalized by comparison with Atomics International organic and AMF Atomics boiling studies that assume a ship built two years later

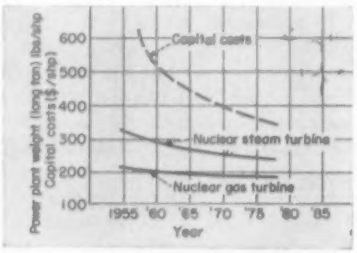


FIG. 4. Prediction of plant weight and cost reduction. Two lower curves slant down, yet depict plants optimized for economics, not lowest weight. Plants could be built even lighter, but only at some sacrifice of cost factors

TABLE 2—Tanker Comparisons

	38,000 DWT tanker		*85,000 DWT tanker*	
	Conventional	*Nuclear*	*Conventional*	*Nuclear*
Length, ft	667	667	890	890
Speed, knots	17	17	17	17
Shaft horsepower	17,000	17,000	32,000	32,000
Hull costs, ($)	8,400,000	8,400,000	20,400,000	20,400,000
Propulsion plant, ($)	3,000,000	9,000,000	5,000,000	15,000,000
Operating costs/yr, ($)	2,045,200	2,726,700	3,887,500	5,005,800
Fuel costs/yr, ($)	460,000	750,000	865,000	1,340,000
Amortization, ($)	684,000	1,044,000	1,522,000	3,120,000
Tons carried/yr @ 5.3 trips	170,000	187,500	383,000	452,000
Cost/ton carried, ($)	12.00	14.50	10.00	11.80

approach 200 lbs/shp in the 20,000-shp range (see Table 1).

Economics. Ideally, a ship best suited to nuclear power is one that operates on long trade routes, capable of quick turn-around, carrying dense cargo and operating at high speed.

Thus it appears that nuclear propulsion can in the next 10 years improve the earning capacity of a number ship types, including tankers, bulk carriers, and possibly liners

Lacking practical experience in the construction and operation of commercial nuclear vessels, it is extremely difficult to project into the future what little firm information is now available. There is no obvious reason, however, why nuclear power plants installed in merchant ships need be more expensive than their land-based cousins. In fact the advantage may be with the ship reactor, which could be partially fabricated and completely assembled in well-equipped shipyards.

Economic optima. Disagreement may exist with respect to an optimum reactor system; there is however no difference of opinion based upon economic factors regarding the ideal initial ship for nuclear propulsion. That type is the super-tanker on the Persian Gulf—U. S. run.

Let us consider the tanker and analyze where it stands in its ability to utilize nuclear power profitably. Assume the vessel is launched in 1961 and is powered by reactor type X—probably a pressurized-water, boiling-water, or organic-moderated system, as indicated above. In this case we shall exclude research and development costs, and compare the effects of power and size on cost per ton of cargo carried in conventional and nuclear ships (see Table 2). A ship speed of 17 knots was arbitrarily selected since all cases examined to date show maximum profits will be made at speeds under 18 knots.

Power costs for conventional tankers of 20,000 shp run about $0.35 per million Btu or about 0.50 lb of fuel per shaft horsepower hour. Nuclear vs conventional fuel costs on an annual basis are shown in Fig. 2 for tankers on the Persian Gulf run.

Figure 3 is a plot of the capital cost results of a series of studies on pressurized water, boiling water, and organic moderated systems for a super-tanker launched in 1961—a year after the first ship sails. All capital costs are based on U. S. construction estimates. The reactor system X used in the economic comparisons above were based on a mean case that is probably realistic since costs will probably be lower than the pressurized water reactor in the first ship but more than the boiling water reactor estimates.

Figure 4 attempts to predict what advances one might expect in propulsion plant weight reduction and capital costs in the period 1957–1975. The effects of standardization have not been included in these projections.

There is good reason to believe that early in the 1960's it will be possible to achieve the beginning of standardization — to construct five or more identical propulsion plants for domestic and foreign maritime applications

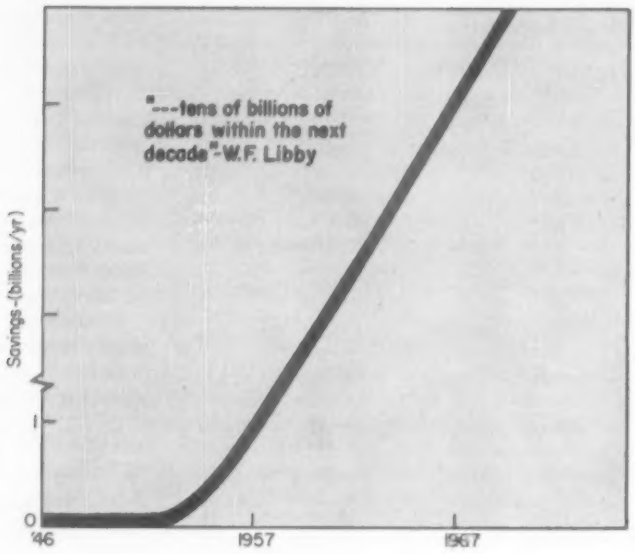
The next step. Underlying these economic and technical considerations is the need for early participation of private operators in the development and operation of nuclear ships. Without their interest and patronage, we will lose the early lead we now hold in nuclear propulsion technology.

It is reasonable to assume that a second and possibly a third nuclear ship could be launched within a year after the first. One may then hope that by the end of the next decade the tempo of nuclear ship construction will increase and include other ship types, possibly the fast passenger vessel.

Undoubtedly the most uncertain aspect facing the entrance of nuclear ships into domestic and foreign commerce will be the need to acquaint and convince various regulatory, supervisory, technical, health and operating bodies of the general acceptability and safety of nuclear vessels. This is not to imply that these bodies are unsympathetic to this new mode of propulsion, but rather reflects a wide variety of opinion regarding the degree and approach to the operating ground-rules that will ultimately govern operation of nuclear vessels.

This must be recognized as only the first step, since we must participate in a similar way with their foreign counterparts. While it is doubtful whether complete unanimity can be reached, it is reasonable to believe that the first ship will operate in foreign commerce under possibly modified operating procedures but otherwise unrestricted within a reasonable period after its initial voyage.

In conclusion, it should be said that we have just started to open the door to commercial propulsion. What we have seen looks encouraging. Obviously nuclear propulsion will not in itself be a cure-all for the American merchant marine. It will, however, permit ship operators to gain the initiative by increasing the productivity of individual vessels. The extent to which nuclear propulsion lives up to its early promise lies in the future, still behind the partially-opened door.



AEC estimates indicate that industry's growing savings from the use of radioisotopes are already in the neighborhood of $1-billion/year

radioisotopes

By WILLARD F. LIBBY

THE NEXT DECADE will see the emergence of radioisotopes as one of the foremost peaceful dividends from United States atomic investment, the most important being peace itself. While atomic power is continuing its development toward economic parity with fossil fuels, radioisotopes already have established themselves as an important adjunct to our technology.

Within the next decade the economic value of radioisotopes may be measured in the tens of billions of dollars

The contribution of radioisotopes to the national welfare will redound to the benefit of the entire citizenry. Realization of these goals will be limited only by availability of the raw materials of progress—men, money, and vision.

In the first decade of the Atomic Energy Commission's isotope program, industrial radioisotope applications have yielded substantial savings to the national welfare and economy. Currently, these are on the order of one half billion dollars a year. These benefits have resulted from a minimal exploitation of the potential use of radioisotopes in industry. Presently, only one-third of one percent of the industrial manufacturing and mining concerns in the United States are engaged in the use of these materials. It is therefore apparent that the benefits derived from radioisotope use to date represent but a fraction of their maximum potential. As in the case of many conventional industries, these benefits ultimately will accrue, but it may take tens of years. Relatively slow growth in economic value and market penetration characterizes even obviously valuable industrial techniques. This pattern has been exhibited thus far in the case of radioisotopes. There is good evidence, however, that we are now on the threshold of a new surge of growth in radioisotope use.

Much of this future growth will derive from increased market penetration of already developed industrial applications of radioisotopes. The market for radioisotope thickness gages, for example, is estimated to be only about 10% saturated. Uses already developed for Kr^{85}, tritium, Pm^{147}, and Sr^{90}, as in self-luminous sources and atomic batteries, indicate a potential multimegacurie-per-year demand for these isotopes as well. It is estimated that market requirements shortly will absorb annually 3,000,000 curies of tritium and 100,000 curies of Kr^{85}. This potential market exists despite the fact there has been no active sales effort by industry. Similarly, experimental neutron gages for measurement or control of contaminants or constituents of products and for moisture determination, other thickness gages for measurement of very thin films—fractions of a milligram per square centimeter—and internal gaging using radioisotope sources fixed in a subsurface material all have been but little exploited to date but may be expected to play important roles in the future.

Based on past performance, substantial further growth

will be realized from the combination of radioisotopes and electronics, for in some instances nuclear radiation detectors may prove to be ideal sensing devices in electronic automation equipment.

The greatest growth, however, is likely to result from radioisotope applications in the mass-production industries for low-level tracing and high-level irradiation. These applications contain the seeds of a new industrial revolution.

We can now envisage manufacturing processes wherein small quantities of radioisotopes routinely would be added directly to the product components at some intermediate stage. The types and amounts of radioisotopes involved would be well below any amount that would affect the health and safety of the public. The application is possible only because of extremely sensitive measurement techniques. In this way, the radiation emitted by the low-level concentrations will provide means for continuous industrial tracing and process control. Minute quantities of beta-emitting radioisotopes added to crude oil, for example, will provide the petroleum industry superior means for continuous monitoring of the efficiency of the catalytic cracking process and determination of the constituents and contaminants of the hydrocarbon products.

In view of the huge reservoir of carbon and hydrogen contained in articles of commerce, it is apparent that C^{14} and tritium will find widespread use for tracing and controlling the manufacture of such articles. Industrial processes dependent upon mixing, flow, distribution, location, composition, and other process variables are amenable to elucidation, tracing, and control by low-level techniques. Since virtually all manufacturing involves one or more of these variables, low-level radioisotope technique probably will become a standard tracing-and-control system in the process industries within the next ten years.

Useful effects from the interaction of radiation with matter already have been demonstrated. Improvement of the physical properties of materials, rearrangement of their molecular organization, and changes in their biological state all can be accomplished by radiation. Irradiated polyethylene, for example, possesses unique properties not observed in the standard polymer. Graft copolymers can be prepared, and a variety of chemical reactions—such as halogenation and oxidation—can be induced by irradiation. Foods and drugs can be sterilized. Unique reactions not otherwise feasible become accessible through the agency of radiation.

Already approximately 60 industrial and research concerns have been licensed by AEC for a total of 300,000 curies of Co^{60} to be used for radiation research and development. Indeed, were adequate and continuing quantities of Co^{60} readily available at an economic price, it is likely that pilot plants employing a total of 5 megacuries of Co^{60} would come into being within a short time. Within 5 to 10 years, requirements for Co^{60} for full-scale-production operations might well reach 10 or more megacuries per year.

Cesium-137 also could become an outstanding radioisotope for commercial-scale radiation applications. Little interest in this radioisotope for large-scale industrial use has been expressed to date, but this probably is due, at least in part, to its present high price and severely limited availability. Opportunity to study its potential will become available to industry late in 1957, when production of 200,000 curies of Cs^{137} per year at the Oak Ridge National Laboratory multicurie fission product pilot plant will be initiated.

There is good reason to believe that the price of radioisotopes could drop sharply if the volume were to increase by several orders of magnitude. Indeed, based on our experience in the irradiation of target materials in our production reactors and our experience in fuel-element reprocessing, we should be able to envision, under very large volumes . . .

. . . Co^{60} at 6¢/curie, Cs^{137} at 30¢/curie, and tritium at 25¢/curie. These prices should catalyze enormously the applications of radioisotopes in industry, agriculture, and medicine

As the nuclear-power industry gets into full swing, we may also expect that substantial numbers of spent fuel elements will be available for use as radiation sources.

The benefits of radiation applications such as these of themselves may well repay the cost of the entire atomic energy program.

Thus far, we have been principally concerned only with the replacement value of radioisotopes; i.e., their potentialities relative to conventional techniques. It is likely, however, that a contribution to the national welfare and economy equal to that from all other radioisotopes uses combined may be made by as-yet-undiscovered applications—the "unborn" uses of radioisotopes. The opportunities in this realm are limited only by the human imagination. Many industrial firms boast that the products they sell today had not even been conceived of ten years ago. So may we say the many radioisotope applications ten years hence have not yet penetrated even the subconscious of our most erudite scientists. Although we cannot now place a specific dollar value on these unborn uses, we can state qualitatively that their worth is equivalent to the value at which we capitalize an original thought.

Growth in radioisotope use, adoption of low-level techniques, the "era of applied radiation," and development of unborn uses all point to industry coming into the field of

Willard F. Libby

Scientist member, U. S. Atomic Energy Commission; shown (above) in Washington Laboratory where he still works on the radiocarbon dating method he developed.

isotope production. In fact, the economic feasibility of isotope production by private industry is even now approaching reality.

An entirely new atomic-energy industry will rise within the next ten years—private-enterprise production of radioisotopes

Additional growth of the radioisotope market sufficient to support such private undertakings is certain to be realized in the near future. Opportunity thus will be available to operators of the numerous private research reactors which will be in use throughout the country to obtain revenue by supplying short-half-life radioisotopes to local markets in their vicinity. Similarly, space that can not be otherwise employed in private test reactors can be utilized to produce a variety of radioisotopes for sale to industry. For radioisotopes for which an unusually large demand is likely to develop, such as Co^{60} and tritium, private industry may construct a few reactors specifically designed to produce them.

Perhaps the most intriguing role in private isotope production will be played by power reactors. Not only can they serve our power needs; they can serve our requirements for radioisotopes as well. Under these circumstances the efficient nuclear power station of the future will not be designed solely to produce power. Facilities for production of Co^{60}, tritium, C^{14}, and other radioisotopes needed by industry will also be provided. In addition spent fuel elements will be rented to industry for use as radiation sources prior to being chemically reprocessed. The valuable fission products also will be utilized. Instead of being treated as wastes, they will be chemically separated and sold for use in industry.

The Atomic Energy Commission supports development of this new American industry. As private enterprise assumes its proper role as the nation's radioisotope manufacturer, the role of the Atomic Energy Commission in this area will be correspondingly reduced.

Realization of the future of radiation envisaged here hinges on maximum utilization of the raw materials of progress—men, money, and vision. We do not now have sufficient numbers of technical people conversant with the technology and potentialities of radioisotopes to permit advantage to be taken of their benefits. It is imperative, therefore, that we begin at once to develop our most important natural resource—men.

Milestones in Growth of U. S. Isotopes Program

RADIOISOTOPE USE *has grown by a factor of about 10,000 in the past decade. In the last half of 1946, 83 institutions received 280 shipments averaging 30 mc per shipment. In the first half of 1957 more than 4,000 institutions received more than 30,000 shipments averaging nearly 3 curies per shipment.*

The following is a list of some of the milestones in AEC radioisotope distribution during the past decade. It was prepared for NUCLEONICS *by Paul C. Aebersold, who signed the first reactor-isotope allocation in July 1946 in his capacity as chief of the isotope branch of the research division of the Manhattan Project. He is now assistant director for isotopes and radiation of the Division of Civilian Application of the U. S. AEC.*

1946, August. First public distribution of reactor-produced radioisotopes.

1947, March. Initiation of reactor service irradiations.

1947, July. First compound labeled with radiocarbon (methyl alcohol) available from AEC.

1947, September. Routine availability of chemically processed radioisotopes with standard specifications.

1947, September. Initiation of international distribution of radioisotopes. (First International Atoms for Peace Program.)

1948, January. Formation of permanent Advisory Committee on Isotope Distribution (replacing interim policy committee set up under Manhattan Project).

1948, January. Enactment of regulations by the Interstate Commerce Commission for shipment of radioisotopes by rail and truck.

1948, April. Initiation of a program making available free of production costs three isotopes—radiosodium, radiophosphorus, and radioiodine for research, diagnosis, and therapy of cancer and allied diseases.

1948, June. Opening of first AEC-sponsored training course in basic radioisotope techniques by Oak Ridge Institute of Nuclear Studies.

1948, July. Beginning of production and distribution of radioisotope-labeled compounds by commercial firms.

1949, February. Extension of Commission's program for support of cancer research to include the availability of all normally distributed radioisotopes free of production costs for use in cancer research.

1949, July. Enactment of regulations by the Civil Aeronautics Board for shipment of radioisotopes by commercial aircraft.

1950, March. Completion of new large-scale radioisotope-processing facilities at Oak Ridge National Laboratory.

1951, January. Availability of broad institutional licenses for those institutions experienced in research and development with radioisotopes.

1951, March. Elimination of requirement for publication of results obtained with AEC-produced radioisotopes.

1951, April. Initiation of a program to stockpile a variety of important radioisotope-labeled compounds and make them available through Oak Ridge National Laboratory.

Increasing emphasis must be placed on training of scientists and engineers in radioisotope technology. This job should not be left to our educational institutions alone. Though their responsibility is great, it is industry that has the most at stake. It would seem to be a simple matter of enlightened self-interest for industry to pool its resources in a program to encourage our youth to pursue atomic-energy careers and to finance in part the physical plant necessary to provide adequate training. Training must be provided not only tomorrow's student, but today's practicing engineers and scientists. The latter is necessary in order that we can take full advantage of the opportunities in the field of radiation that are immediately at hand.

I suggest that if each industry trade association in the United States devotes a portion of its budget each year for the next five years toward encouraging radioisotope training, we can overcome our deficiency in this natural resource. In the absence of some such effort, the future of radioisotopes in industry will be dimmed substantially.

Complementing its training programs, industry also must make available risk capital. This is as much the life blood of the radiation industry as it is of every other industry. There appears to be a tendency to consider investment in the radiation industry as an exotic venture. This view is not justified; investment in radioisotopes is a straightforward business proposition and should be evaluated as such. Radioisotopes already have proved their worth. It is now up to industry to have the courage to capitalize upon them.

Perhaps the most important of the raw materials of progress is vision. Our great material well-being of today is rooted in the creative imagination of the past. So, too, will the rewards from radiation in the coming decade be proportional to the vision we exhibit now.

We might well consider joint industry-government sponsorship of what might be called an Isotopes Development Program

The potential contribution of radioisotopes to the national welfare and economy in the future is so vast as to justify a major effort to accelerate its early realization. It would seem to be good business sense to plow back 5–10% of present savings into such an effort. In the interest of paving the way toward realization of this potential contribution and permitting us to benefit therefrom more quickly, we should seek new means of cooperation.

1951, April. Publication in Federal Register of regulations governing radioisotopes distribution, including designation of "generally licensed" quantities (requiring no license application.)

1951, November. First radioisotope (I^{131}) accepted by Federal Food and Drug Administration as effective new drug.

1952, January. First film of eight-part radioisotope training film series, "The Radioisotope," made available for training in radioisotope techniques.

1952, June. Availability of licenses for use of radioisotopes by physicians in private practice.

1952, June. Revision of AEC Cancer Program to make most radioisotopes available at 20 per cent of catalogue prices.

1952, August. Simplification of procedures for import of radioisotopes into U. S. from Canada.

1953, January. Announcement of facilities for irradiation of large items at Brookhaven National Laboratory.

1953, December. Atomic Energy of Canada, Ltd., announced that holders of broad licenses for radioisotopes procurement in the United States are eligible to obtain similar Canadian licenses.

1954, January. Publication of list of 492 isotope-labeled compounds available from 13 commercial suppliers, the National Bureau of Standards, and Oak Ridge National Laboratory.

1954, July. Revision of Federal Radioisotopes Distribution Regulations to cover radioisotopes produced in any publicly or privately owned nuclear reactors in the United States, its territories, or possessions.

1954, August. Enactment of Atomic Energy Act of 1954 changing certain provisions for the distribution of radioisotopes.

1954, October. Appropriation approved for Multicurie Fission Product Separation Plant to be located at Oak Ridge National Laboratory.

1955, July. Large-scale production of high-specific-activity Co^{60} begun at AEC's Savannah River Plant.

1956, January. Isotopes Division made part of Division of Civilian Application, the division established to carry out the Commission's civilian-use activities.

1956, February. Radioisotope licensing procedures revised to permit a "possession limit" rather than a "total quantity that may be procured."

1956, February. Simplification of international distribution of radioisotopes, permitting U. S. licensees to export radioisotopes of elements 3 to 83.

1956, February. "Generally licensed" quantities of radioisotopes increased, permitting wider use and interchange of small samples without filing an application.

1956, August. Records relating to radioisotope licenses made publicly available in AEC's Public Document Room.

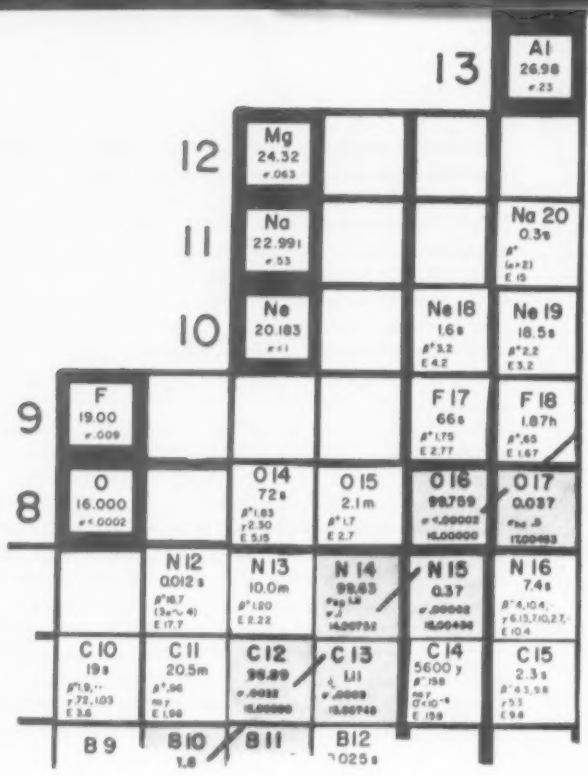
1957, January. Issuance of a Federal Regulation, Title 10, Part 20, establishing general regulations for protection against radiation.

1957, Fall. Opening of Multicurie Fission Products Pilot Plant at Oak Ridge National Laboratory.

1957, Winter. Completion of Multikilocurie Fission Products Pilot Plant at ORNL.

nuclear physics

By GERTRUDE SCHARFF-GOLDHABER



EVEN A SUPERFICIAL GLANCE backward will teach us that it is impossible to predict in detail the future of a fast-moving science like nuclear physics. It will remind us that often entirely unexpected events changed the direction of endeavor in this field. These events were either of an experimental nature, as, for instance, the finding that beta rays have continuous energy spectra, or they consisted in the formation of new concepts—as, for example, of the liquid-drop model of the nucleus.

It is, of course, similarly impossible to predict what extraneous happenings may in the future affect scientific progress as profoundly as two world wars and political persecution have affected it in the past. During the last twelve years the great importance attached to atomic energy has induced an unprecedented increase in the tempo of research, and new nuclear physics centers have sprung up all over the world. This development is viewed by many with delight while others are afraid that it may have a negative effect on nuclear physics as a pure science.

In spite of all the uncertainties mentioned, it is useful to interrupt from time to time one's preoccupation with the problem at hand to investigate the trends that current research seems to follow, both in experiment and theory, and to try to recognize how far these may serve to bring us closer to the solution of outstanding problems.

The central problem is to understand the nucleus in the same sense in which one might have said in 1926 that the atom was understood: one knew then not only that the forces between the nucleus and the atomic electrons were pure Coulomb forces, but also that the excited states in which the system could exist were governed by the laws of quantum mechanics, including the Pauli exclusion principle. (It is true, only the states of the simplest atom, hydrogen, could be exactly calculated, while already the helium atom presented such overwhelming mathematical difficulties that it took about another quarter century and development of computers to reach the same stage.)

If we want to study events happening inside the nucleus, its finite extension and the distribution of charge and current inside it, we have a task of a higher degree of difficulty than in the atomic case: (a) We do not know the exact nature of the force between two nucleons, nor do we know whether a potential exists for this force. (b) One cannot consider, in first approximation, the interaction of two nucleons only, because all nucleons are close to each other. (c) We do not know whether the laws of quantum mechanics are sufficient to describe a nucleus completely.

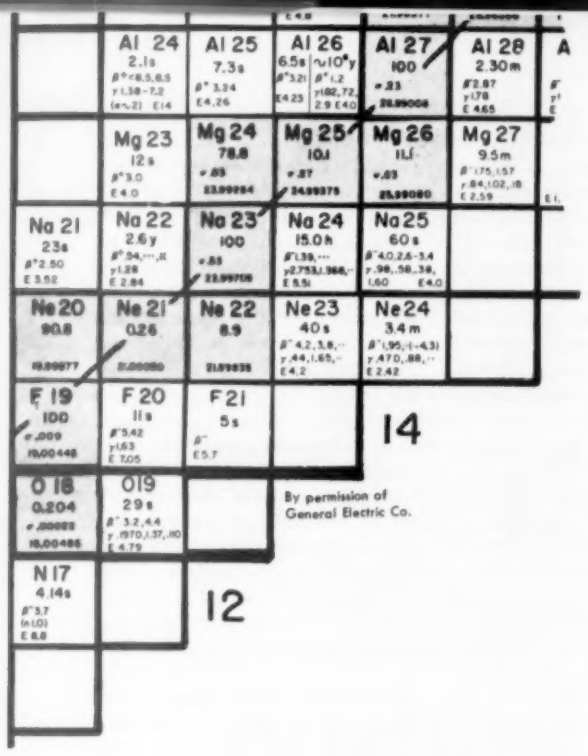
Quantum mechanics may need to be modified, e.g., by the introduction of the concept of a fundamental length, before nuclear phenomena can be explained

On the other hand, we have two important clues on the nature of nuclear forces:

1. Apart from the lightest ones, all nuclei have the same density $\rho = 1.7 \times 10^{38}$ nucleons/cm^3, at least in their central part, so that it is reasonable to speak of "nuclear matter." Hence, if it were not for the Coulomb repulsion between the protons, nuclei of arbitrarily large size would exist. We therefore speak of the "saturation" of nuclear forces, which prevents nuclear matter from collapsing to a density less than ρ and from flying apart.

2. Experiments have shown that the forces between two protons, corrected for the effect of Coulomb repulsion, are the same as between two neutrons, i.e., charge symmetry prevails, and probably the forces are also the same between a proton and a neutron (charge independence).

In recent years a number of theoretical physicists, under the leadership of K. Brueckner, have tried to understand the nuclear phenomena by treating the nucleus as a many-body system assuming that nuclear forces can be derived from a two-body potential. The simplified case of infinite



nuclear matter is considered first. A few months ago P. S. Signell and R. E. Marshak and independently J. Gammel and R. Thaler showed that the phase shifts derived from nucleon-nucleon scattering experiments up to 150 Mev can be fitted remarkably well by a charge-independent potential including a spin-orbit term of the same sign as in shell theory. This potential has already been introduced in a Brueckner-type theory by de Dominicis, and reasonable answers for the binding energy of infinite nuclear matter have been obtained.

One would hope to apply similar methods to the more complicated case of the finite nucleus, thereby demonstrating the validity of the shell model for such a system. The next decade may see an understanding of complex nuclei based on interactions derived from nucleon-nucleon scattering experiments.

While the solution of these very difficult fundamental problems progresses slowly, experimental nuclear physicists are guided in their research by a number of more phenomenological nuclear models, each one of which is limited in its application. Usually these models are not born in a finished form but have to be modified continuously to fit the facts. Sometimes, they even seem to contradict fundamental principles, as when the basic assumption of the shell model that a nucleon may be considered to move in a central potential seemed at first to violate the idea that the mean free path of a nucleon is of the order of its diameter. J. H. D. Jensen, in a talk given in 1956 at the International Congress on Theoretical Physics in Seattle, recounted how Maria Mayer and independently Haxel, Jensen and Suess revived and modified—by the introduction of strong spin-orbit coupling—the early shell-model ideas (which in turn were conceived in analogy to the atomic case) merely as a working hypothesis. A possibility of removing the apparent contradiction was first pointed out by Weisskopf, who emphasized the importance of the role of the exclusion principle in simplifying the particle motions in the presence of strong forces. Later quantitative studies of Brueckner, Eden and Bethe have shown that this conjecture is correct and that the shell model can be used to give a useful first approximation to the nucleus up to $\sim$10 Mev.

Two other models which have played an important role in recent years are the collective model developed by A. Bohr and B. Mottelson, which is likewise valid at low energies only, and the optical model, which successfully describes nuclear absorption and scattering processes, e.g., the so-called mountain resonances for neutrons and protons.

Let us now consider some of the aspects of these models which are likely to lead to further progress in nuclear research: The shell model will, of course, continue to be useful for the construction of level schemes and in giving the characters (spins and parities) of levels not only of stable nuclei, but also of radioactive nuclei, in providing a means for the classification of beta decays and for the explanation of the occurrence of nuclear isomers, etc. Of more far-reaching importance are the possibilities for a quantitative analysis of the energies of nuclear levels. In the near future such an analysis will be restricted to the immediate neighborhood of doubly magic nuclei, e.g., O^{16} and Pb^{208}.

The successful analysis by Elliott and Flowers, by D. Kurath and by B. French and others not only of the level energies of some light nuclei, but also of the transition rates of a number of beta transitions, and of several electromagnetic transitions—mainly of dipole character—justifies the expectation of further progress in this field.

As an example of a field where much progress can be expected in the near future, and in which the author has been particularly interested, a few words may be said about those even-even nuclei which have vibrational level schemes and which lie between the "magic" nuclei and the rotational region. The vibrational level schemes have been tentatively interpreted on the basis of the Bohr-Mottelson model in the region of weak to moderate coupling. Such a model predicts a triplet, of characters 0+, 2+, 4+, at about twice the energy of the first 2+ state. Since states differing in spin by 4 would escape detection with most of the usual methods of determining level schemes, it is not

G. Scharff-Goldhaber

Physics Department, Brookhaven National Laboratory; has worked on nuclear energy levels, neutron and electron diffraction, spontaneous fission, and ferromagnetism.

surprising that only one such close-lying triplet has been found so far, namely, in Cd^{114}. The method used here was the analysis of conversion electrons accompanying neutron capture in Cd^{113} (H. Motz). A systematic search for triplets by means of suitably chosen experiments should throw light on the question of the nature of the vibrational even-even nuclei and, in turn, of those odd-A nuclei of which they form the core.

As is well known, the collective model has been enormously successful in describing not only the level characters and energy ratios, but also the transition probabilities of electromagnetic transitions, the log ft values, etc., in strongly deformed nuclei.

Recent efforts to interpret the level scheme of F^{19} have led to an interesting discovery: the results of one group of physicists who applied a shell-model analysis agreed surprisingly well with those of another group who applied a collective-model interpretation. Ironically, the theoretical values agreed even more closely among each other than with the experimental values. The reason for the good agreement is by no means obvious and is now being studied by a number of theoreticians. It allows one to conclude, however, that it will be possible to set up a unified model of the nucleus, in which the individual particle motions and the collective motions are self-consistent as in molecules. Important attempts in this direction have been made by Peierls and Yoccoz and by Wheeler and Griffin.

Now a few words about higher-energy nuclear reactions: As was mentioned above, the optical model is successful in describing the energy dependence of the absorption and scattering cross sections of the particles impinging on a nucleus for a considerable energy range. However, a theory has still to be evolved which will give the probabilities and angular correlations for the decomposition of the system target nucleus plus bombarding particle into the various energetically allowed end products. It may be added that the optical model is based on the assumption that the energy spectrum of the incoming particles overlaps many resonance levels in the target nucleus. It is likely that with increasing energy definition this approach will give way to a renewed interest in the fine structure, which is of particular importance in the fission process.

We can look forward to definitive progress toward understanding the bewildering variety of phenomena observed in fission

A few thoughts on beta-decay theory: the recent revolution in thought brought about by the discovery that parity conservation and the conservation of charge conjugation do not hold in weak interactions has attracted great interest to this field. Although at present the nature of the interactions for the nucleon-electron-neutrino system is not known, it is very probable that by the end of the coming decade it will be quite well understood. This will be brought about by studies of polarization of the electrons emitted in various types of beta decay, by further efforts to detect double beta decay and by the refinement of present neutrino-detection experiments.

The experimental determination of nuclear properties will increase in accuracy and scope as the equipment and methods grow in diversity and ingenuity.

For example, the steady improvement in resolution and efficiency of spectrometers will facilitate the determination of level energies.

For character assignments to nuclear energy levels there are now a number of methods at our disposal, which we have just begun to exploit. For short-lived states preceded by some previous radiation there is the delayed-coincidence method, which Sunyar has recently developed into a form that permits one to measure lifetimes as low as a few times 10^{-11} sec. For electric dipole or quadrupole transitions leading to the ground state the Coulomb-excitation method is able to cover a wide lifetime range. As a final example, the use of molecular-beam and paramagnetic-resonance methods for the spin determination of radioactive nuclei will doubtless increase and serve to check assignments made on the basis of decay-scheme studies. Further, it may be expected that the refinement of the theoretical interpretation of experimental results, e.g., a better theory of stripping, of internal conversion and of the angular distribution of inelastically scattered particles, will make level-character assignments of excited states more definite.

Radioactive nuclei will be found further away from the stability region, owing to the use of heavier bombarding particles and faster detection methods. The study of the binding energies of nuclei of this type may throw further light on the nature of nucleon-nucleon forces. Also, the number of known elements will certainly be increased.

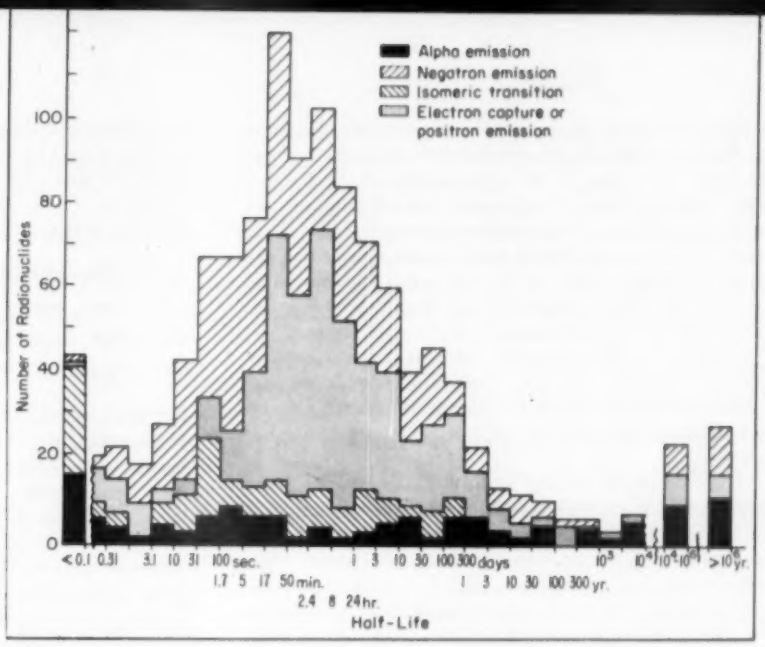
Relatively long-lived isotopes may well be found among the far-transuranic nuclides because of magic-number stability

There may be, for instance, another region of relative stability at the doubly magic nucleus $_{126}X^{310}$ (the closing of the j neutron shell).

New accelerators like variable-energy cyclotrons and tandem Van de Graaffs capable of producing beams of well defined and sufficiently high energies will make it possible to study radiation and particle widths of excited states of light nuclei with accuracy, thus testing the shell-model wave functions, and to explore the level schemes of medium-weight nuclei ($50 < A < 150$).

Atomic-beam methods and possibly the study of μ-mesic X-rays will yield new data on electric and magnetic moments of higher order. The boldness of some thinkers in this field is indicated by the title of a recent theoretical paper: "Nuclear Hexadecapole Moments." It may even be possible to get a better idea of the charge and current distribution within the proton by means of the 6-Bev electron synchrotron now being constructed at Cambridge, Massachusetts, which will permit an extension of the very successful work carried out at Stanford.

One important goal of nuclear-physics research is the deduction of nuclear forces from meson fields. Among these fields the role of the π-meson field will probably be first understood, but it is clear that any ultimate theory will not be able to ignore the role of the "strange particles" (K mesons and hyperons). In the meantime, the new field of "hypernuclear" physics is likely to develop considerably and to help indirectly in the understanding of nuclear phenomena.



NUCLEAR SPECIES identified by nuclear chemists and recorded by W. H. Sullivan display a gaussian half-life distribution. They are classed here according to principal mode of decay and grouped logarithmically by half-life

nuclear chemistry

By CHARLES D. CORYELL

NUCLEAR CHEMISTRY is an old field, born simultaneously with nuclear physics and intimately connected with it ever since. Even its industrial analog, radiochemical engineering, had to be invented by Marie Sklodowska Curie before radium could be identified. But radioactivity and radiochemistry have been dominated by physicists, and their chemical challenges have been largely ignored among chemists.

The fantastic development of atomic energy for military purposes under the Manhattan Project showed the need for nuclear chemistry without, however, affecting very much the attitude of the academic and industrial research world. Only in the last year or two has the exciting pull of a competitive civilian atomic-energy industry started to stimulate chemists' circles. Nuclear chemistry cannot fail to come along now, pulled by the greater enthusiasms and activities in nuclear physics, nuclear engineering, and radiobiology and also, if the reader will permit the recognition, nuclear political science.

A traditional activity of nuclear chemists has been the search for and identification of nuclear species. During the last decade, the number of known radionuclides has doubled, and now most new species will be discovered with increased skill in handling shorter-lived materials. A review of the half-life distribution of the 1,160 currently known radionuclides is given in the accompanying graph. The most prominent half-life for β^- and electron capture (EC) decay is about 1 hr, and it would appear that the distribution is roughly gaussian around this number. It is easy to show on theoretical grounds that this is illusory, and that there is a large number of short-lived β^- and EC species to be found down to a half-life of about 0.01 sec. This lower limit is set by that of zero neutron or proton separation energy. On the other hand, it is likely that all but six or eight long-lived species ($T_{1/2} > 1$ yr) for Z less than 95 have been discovered, which will fit in the right of the graph.

The big advances since 1947 in nuclide discovery are: the synthesis (mostly at Berkeley) of a large variety of nuclides beyond uranium and of a new group of α emitters just above Sm^{146}; the recognition of many new isomers and a systematic search for very short-lived isomeric states; and the synthesis of many new neutron-deficient nuclides (EC decay) in spallation reactions studied at high-energy machines.

The push to higher atomic number has involved the use of multiple neutron capture in a high-flux reactor like the MTR or in bomb tests and also the bombardment of high-Z atoms with C^{12}, C^{13}, N^{14} and O^{16} ions accelerated in the cyclotron.

G. Seaborg and I. Perlman have been leaders in establishing interesting regularities in the decay energetics of the heavy elements.

One of the most interesting developments in nuclear theory has been the independent-particle–nuclear-shell model, proposed independently in 1949 by Maria G. Mayer and O. Haxel, J. H. D. Jensen, and H. E. Suess. This has helped correlate nuclear data and been the basis for numerous new experiments. A radical extension particularly valuable in regions between shells is the collective model (1953) of A. Bohr and B. R. Mottelson. These developments stimulate and challenge nuclear chemists.

Two special aspects of theory should be mentioned here. One is correlation of nuclear energetics, mentioned already

for heavy elements. Corresponding treatments of β^-- and EC-decay energetics, with reference to shell effects, have also been given (Coryell, R. A. Brightsen, A. C. Pappas, 1953). Indeed there is growing interest in formulation, on semitheoretical basis, of the nuclear mass-surface. A. E. S. Green and coworkers (1953) have sought regularities and probed out shell offsets. H. B. Lévy (1957) has exploited a simple but effective equation, and a table of his extrapolated masses has been computed over a broad range by J. Riddell in a 1957 report of the Chalk River Project. Still more recently, A. G. W. Cameron has developed, also as a 1957 Chalk River report, a more sophisticated formula with tabulated calculations that should interest nuclear chemists.

Another open theoretical problem is the explanation of the fission reaction. The problems of chemical separation and the chemical implications of fission have put chemists in a strong experimental position in the field of fission. Recent reviews (E. P. Steinberg and L. E. Glendenin and A. C. Pappas, 1955 Geneva Conference) have stressed fission yields, but an interesting over-all critique of the problems of fission has recently appeared in a 1955 Chalk River report. Theoretical descriptions have not come very far. They fall into two classes: a statistical theory of P. Fong (1956), assuming approach to equilibrium between the separating fission fragments, and a hydrodynamic theory of N. Bohr, J. A. Wheeler and D. L. Hill (1939, 1953), which was rather effectively exploited by W. J. Swiatecki (1955–6).

The coming decade will provide a detailed theoretical explanation of fission

The relentless process of radioactive decay provides a method of determining age if the original amount of some radionuclide and the final amount are knowable. One of the neatest examples of this type is the use of cosmic-ray-produced C^{14} to tell the time of removal of carbonaceous materials from the biosphere. This method, due to W. F. Libby (1946), has been of great value in setting ages of specimens covering a range backwards from the present of about six half-lives of C^{14}, or about 33,000 years. This range is of great interest in archeology. The use of the method is spreading, and increased care in making measurements will cast light on constancy of cosmic rays during the time range.

Charles D. Coryell

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Cosmic-ray-induced tritium can perform a similar service over a scale based on its 12.3-yr half-life, e.g., for measuring the flow of underground water bodies or undersea currents. The problem is made more complicated by large amounts of tritium produced in bomb tests.

Interesting results on atmosphere circulation, water turnover and hydrogeology may be expected through the use of tritium tracers

The uses of radioactivity in geologic dating have become so important that the field of nuclear geology is becoming recognized. This is, however, just a specialization of nuclear chemistry in geologic environment for geologic problems. Age determinations depend mostly on identifying the various lead isotopes produced in the decay of U^{238}, U^{235} and Th^{232}, in determining the helium produced in such decay, or in determining A^{40} produced in the decay of K^{40}, or Sr^{87} produced in the decay of Rb^{87}. There are a number of other interesting problems growing out of the occurrence of long-lived natural radionuclides.

Several people, including W. A. Fowler, A. G. W. Cameron, J. L. Greenstein and P. Fong, have been able to make a breakdown of reactions in heavy-element nucleogenesis into neutron capture on a slow time scale, neutron capture on a very fast time scale, and some photodecomposition to make neutron-deficient species. These interpretations will be improved with increase in our knowledge about very unstable nuclei and the effect of nucleon shells on nuclear dynamics.

The needs of the atomic-power industry have already begun to impress themselves on analytical chemistry. Standard procedures are available for the isotopic analyses of a number of elements, in particular uranium and plutonium. Mass spectrography of light elements, with gas samples of the elements C, N and O and deutero-organic compounds, is commonplace. The solid-source spectrograph promises soon to be important in general analysis, since for some elements mass spectrography promises the best sensitivity available.

The spread of nuclear reactors and improved discrimination among induced radioactivities will spur analysis by neutron activation

The problems of identification of fallout from bomb tests and the similar ones of determination of the origin of fission products and activation products in the components and working environment of power reactors have led to the development of many improvements in analyses and forced an increase in the reliability of the determinations in low-activity sources. Correspondingly, there is a feedback from radiochemical analysis that strengthens all of analytical chemistry in the speed and detail with which analytical separations and determinations may be tested with radioisotopes. Perhaps the most dramatic example of this interplay is in the tremendous growth in the understanding and use of ion-exchange resins in analytical separations. We expect to see similar developments with other types of analytical techniques.

The monitoring of radioactive products for control lends itself very readily to automation. This type of analytical operation is especially welcome in work with high-level radioactivity or with the very toxic transuranium species. Indeed, operating laboratories in atomic energy are about the best equipped for automatic operation in all industry.

Some of the most prominent trends in the industrial applications of nuclear chemistry are being covered in adjacent articles in this series, especially those dealing with nuclear fuels, chemical separations technology and radioisotopes.

There is one special area of industrial development, radiation chemistry, that has a particularly bright future, with a good part of the industrial bases for operation already well shaped up.

There is at present a race between electronuclear machinery and artificial radioactive sources, especially Co^{60}, but spent fuel or by-product radiation from reactors will soon be the cheapest source of radiation

Nevertheless, development work and special applications may continue to depend heavily on electrical machines, mostly van de Graaff or linear accelerators. In an expanding industrial field, variety of sources and variety of methods of use will prevail. The field is an attractive one for imaginative workers, and some very interesting results are anticipated.

There will be much more attention given at national meetings of scientific societies to methods and techniques of industrial interest, and there is already to be seen a growing *esprit de corps* among industrial nuclear chemists

A new spirit will aid in getting broader professional interest in the field, more effective recognition, and a stronger position in technical publication. The radiation chemists already have such an *esprit*, with the Radiation Research Society and an annual Gordon Conference.

One of the first new areas of interest that the nuclear age brought to chemistry is the field of radiation chemistry. There is a growing group of very able people interested in the primary products of interaction of high-energy radiations with matter and the elementary reactions that follow in various systems. A substantial dent has been made in the problems of radiation chemistry in typical aqueous systems, and there is growing attention to organic systems. Considerable interest is developing in colloid systems, especially those of catalytic implication. Activity is high also in radiation polymerization and in radiation effects on semiconductors.

Little has been done in the last decade to improve our understanding of the laws of coseparation. In principle, by detailed study of the laws of coseparation of the tracer of an element, particularly in the field of isomorphous carrying, the chemical properties of that element could be determined in some detail in the given oxidation state. Chemists have not yet worked out the techniques in detail, principally because it has been more attractive to make macro amounts of the element by nuclear syntheses on a large scale. With microgram or milligram amounts of radionuclides of half-lives of months or years, detailed properties have been determined by standard methods.

To solve the problem of determining properties of an element by tracer methods alone would be of great value in establishing the chemistry of the synthetic halogen, astatine (85), the chemistry of which is hardly known, and that of francium (87), which cannot be greatly different from cesium.

Tracer methods would be useful indeed for determining the properties of elements 104 and beyond. The problem stands in any case as one of the great problems of structural chemistry

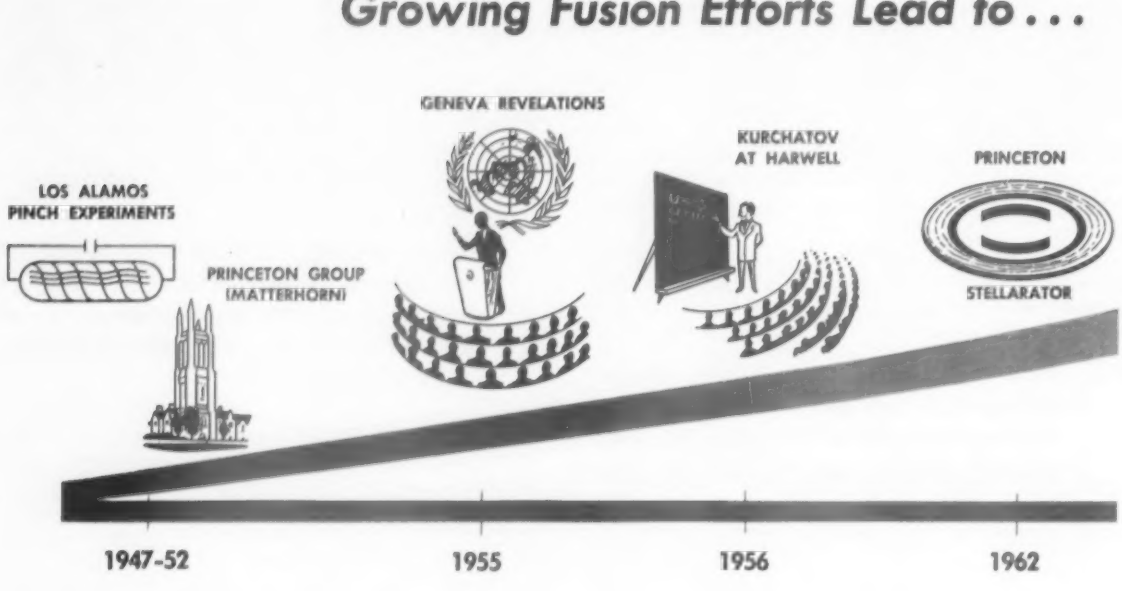
Substantial change in the isotopic composition of molecules is often used for infrared or microwave spectroscopy or nuclear magnetic-resonance studies. There is an increasing facility in incorporating rare isotopes, especially radioactive ones, in molecules to obtain structural information by the powerful new methods of chemical physics.

Physical organic chemistry is coming to lean more and more on the techniques of tagged atoms—using deuterium and mass spectrograph or tritium and counter to follow tagged hydrogen, using these in a C—H bond to tag carbon atoms, using C^{14} for carbon tag, and using readily available tracers such as P^{32}, S^{35}, Cl^{36}, Br^{82} and I^{131} for other substituents. The rather low cost (and low toxicity) of T and C^{14} have encouraged synthetic chemists, and now numerous intermediates are available from private stockpiles and commercial sources.

The field of hot-atom chemistry has grown out from physical chemistry to gain increasing attention from organic chemists, to make recoil syntheses, say from the $N^{14}(n,p)C^{14}$ reaction or the $Li^{6}(n,\alpha)T$ reaction, to put C^{14} or T in complicated molecules. In a given system many tagged substances are formed that may be useful. The yields of various isomers and adducts or other products in such syntheses gives interesting information on the dynamics of the hot-atom substitution. The reaction serves to make tagged molecules of some considerable complication in small but useful yields, although very severe standards of purification must be applied to ensure the integrity of the tagged product. Gas chromatography has proved to be very useful indeed.

The mixture of products formed in recoil synthesis provides an interesting tool to study organic purification processes. It is also possible that a combination of studies of chemical and biological specificities of the products of some systems will cast new light on biological stereospecificity.

It would take this reviewer too far afield to go further into areas of biochemical study with radionuclides, into problems of mineral metabolism (fission-product and more general), or into the nuclear-chemical aspects of radiobiology. Suffice it to say that as chemistry comes closer to biology or medicine, the research workers in the field are oriented more favorably to tracer methods, and there is a tradition nearly 20 years old of seeking out nuclear techniques to help solve difficult problems.



controlled fusion

By AMASA S. BISHOP

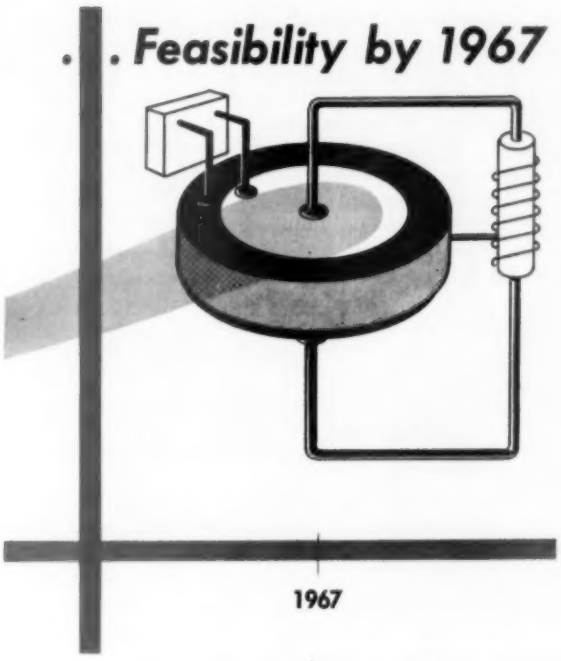
One of the most recent additions on the horizon of nuclear developments is the possibility of energy release through controlled thermonuclear reactions—barely five years old in the United States and still in the early stages of research and development. The problems involved are of both enormous difficulty and unprecedented nature. The potentialities associated with eventual success in this field are, however, of transcending importance.

To learn what the future may hold for controlled fusion, let us briefly review the problems to be overcome and discuss (to the extent permitted) some of the experimental work that has been underway in laboratories around the world during the past five years.

In the United States there has been an intensive and rapidly expanding effort in the controlled thermonuclear field with a number of different approaches being pursued. One approach that I can discuss with some degree of freedom—and that is illustrative of the various problems which one meets in this field—is the so-called "pinch effect." In this approach, a large current is induced to flow in a discharge tube which may, for example, be in the form of a torus. The build-up of this current heats the ionized gas (or "plasma") and simultaneously produces a strong encircling magnetic field which serves both to confine this plasma and to cause it to contract (or "pinch") to a dense hot filament of discharge at the center of the tube. It is hoped that sufficient plasma densities and temperatures may be achieved in this way to produce appreciable fusion of the plasma ions.

The pinch effect suffers, however, from one major difficulty, namely, one of stability. This difficulty, which was predicted theoretically some four to five years ago, arises in the following way: When the plasma is pinched to a fine filament, a small kink of some sort may develop. It may then easily be shown that the magnetic forces on the inside of the kink will be greater than those on the outside, with the result that the kink will grow very rapidly in magnitude. The plasma will then shoot to the walls of the torus within just a few millionths of a second, dissipate its energy there, and quench the discharge. It is thus essential not only to devise a system with adequate magnetic confinement of the individual particles, but one which possesses adequate overall stability as well.

In spite of the severe problems associated with adequately heating and stabilizing such a plasma, scientists in several countries have been vigorously pursuing the approach of the pinch effect for the past few years in the hope that some way could be found to overcome these difficulties. It was soon found, first theoretically and then experimentally, that by decreasing the inductance of the entire system (and thereby permitting the currents to build up very rapidly) the heating of the plasma could be



CONTROLLED FUSION reactor feasibility will be demonstrated by 1967. This is NUCLEONICS prediction based on trend of fusion-world events of last ten years, beginning with first H-bomb explosion and leading up to present frenzied effort on international scale

greatly improved. It was, in fact, found possible to produce neutrons in some of these discharges, and there was intense interest to determine whether or not these neutrons were really thermonuclear in origin (i.e., whether they originate from the fusion of a uniformly hot deuterium plasma in random thermal motion or whether they are produced by just a few plasma ions which have somehow been accelerated to a high energy while the rest of the plasma is relatively cold.)

This problem received detailed study in the U. S. for some time—particularly at Livermore and Los Alamos—and the most likely conclusion is that the neutrons are produced as a result of the instability of the pinch and that they are thus *not* of true thermonuclear origin. To be more specific, the mechanism of pinch break-up can induce very high voltages in the immediate region of the instability, and these voltages will accelerate a small fraction of the deuterium ions to a high enough energy to produce neutrons when they impinge upon other (relatively cold) ions of the plasma.

A great deal of attention has been given to the problem of how to overcome these instabilities. One of the most encouraging approaches in this respect has resulted from theoretical computations made at Los Alamos, indicating that (under certain rather stringent conditions) it should be possible to stabilize the pinch by enclosing axial magnetic fields within the center of the pinched discharge. It must be pointed out, however, that this stabilizing field produces a number of other complications, the severity of which is still to be determined.

Work in the United States is not, however, limited by any means to the pinch effect. In fact, much the same philosophy is being followed in the fusion work as was followed in the fission field—quite a number of different approaches are being actively pursued at various sites throughout the country. An equally major effort is being devoted, for example, at Livermore to a wholly different concept; a third major project, known as the Stellarator, is under active development at Princeton, New Jersey; a still different approach involving shock waves is being pursued at the Naval Research Laboratory in Washington; and other ideas are being pursued at Oak Ridge, New York University, M. I. T., and several other sites.

There has been, in fact, no lack of ideas of how one might proceed in this field; the problem has rather been one of trying to choose which of the suggested approaches are most worthy of pursuit in view of the limitations of the available manpower and funds. Is it better, for example, to start with an appreciable amount of cold gas and try to heat it all up together to a high temperature, or to start with a minute amount of ions with high kinetic energy and attempt to add other energetic plasma particles to it? Is it better to seek a system which hopefully might provide a continuous source of thermonuclear power or to work with a concept which could yield energy only on a pulsed basis? Is it better to develop an approach which is inherently stable, or to try to provide external stabilization of a wobbly system? These are just a few of the problems which must be faced in attempting to determine how best to proceed. As with the fission program, each concept has its proponents, each has its advantages and disadvantages, and each has a host of extremely difficult technical problems to be solved before one can begin to evaluate its relative importance in comparison with the others.

Up to the present time, nearly all of the work in this field has been performed at AEC laboratories or at universities working under contract. With the rapid growth of the experimental effort, however, industry is being increasingly called upon to undertake some task specifically required by one or another of the various sites—e.g., the

Amasa S. Bishop

European scientific representative, U. S. Atomic Energy Commission, located in Paris; formerly, chief, Controlled Thermonuclear Branch of AEC.

development of special systems for energy storage or for the production of ultra-high vacuum, or even the construction and assembly of some of the larger experiments. To facilitate industrial participation, complete information on the AEC program is provided to those firms which are qualified to contribute at this stage to the advancement of the effort. A number of the groups which have gained access to this information have already established their own study projects in the controlled thermonuclear field and are contemplating the initiation of experimental work in one or another phase of the field, either with AEC assistance or even completely with their own funds.

As fusion research moves into the hardware stage, private industry will take over an increasingly larger part

The great interest exhibited by the AEC and by industry in this field is readily justified when one considers the importance of the technological advance that would accompany the successful outcome of such a program.

One of the more important points, for example, is the fact that, in contrast to a fission reactor, there would be little or no radioactive wastes from a full-scale thermonuclear device.*

A second advantage is that any controlled fusion device is likely to be inherently safe. The amount of fuel actually within the reactor at any instant of time would be very small, so there would be no possibility of a "runaway" reaction.

A third point of potentially great importance is the fact that a controlled fusion device offers, in principle, the possibility of *direct* generation of electrical power, thereby eliminating the costly intermediate stage of a heat cycle. This possibility arises from the fact that, with deuterium as a fuel, more than two thirds of the energy would be released as kinetic energy of charged particles. These charged particles would be retained by the confining magnetic field and their kinetic energy could be transformed directly into electrical power.

There are a number of ways in which one could envision the realization of this possibility. Imagine, for example, a plasma confined by a strong externally-generated magnetic field. If now the magnetic field strength were to be slightly increased, the plasma would be somewhat compressed and its density would be increased. Since the rate of power generation goes up with the square of the density, the plasma temperature and pressure would rise rapidly, causing the plasma to expand against the confining field and permitting the direct generation of electricity in adjacent circuitry.

Finally, there is the impressive fact that if and when this program can be made to succeed, man will have tapped a source of energy which is virtually without limit. The oceans contain sufficient deuterium—available at negligible cost—to satisfy all of mankind's power requirements for many hundreds of millions of years.

Recognizing fully the potential importance of this new field, two other world powers—namely, Great Britain and Soviet Russia—have been independently engaged for a number of years in an intensive effort to solve the problems associated with controlled fusion. As in the U. S., the work performed to date has been, for the most part, held classified. Undoubtedly, one of the major factors initially responsible for this classification action was the recognition by each of the countries of the fact that, if successful, the achievement of controlled fusion would provide an intense source of neutrons that could have military significance from the point of view of producing fissionable material. Further to be considered was the fact that the field was in its infancy and that no one had sufficient knowledge or experience to judge the magnitude of the hurdles to be overcome or the likelihood of a "breakthrough" at an early date. At a time when neutrons were still scarce throughout the world and when nuclear power was essentially unknown, these considerations were not to be taken lightly.

During the intervening period, however, the picture has changed quite markedly. On the one hand, the rapid development of fission-type reactors throughout the world has made neutrons and nuclear power much more readily available. On the other hand, the complexities of the field of controlled fusion are now seen much more vividly, and it is becoming increasingly probable that the path or paths toward eventual success will be long and tortuous, with little chance of finding a major short cut.

As a result of these considerations, there appears to be a universal trend toward greater and greater declassification in this field. The trend is an extremely welcome one.

Greater declassification will mean that an increasing number of talented minds throughout the world will be able to participate actively in this challenging field

Projects have sprung up in France, Sweden, and Germany during the past year, following largely the "pinch" approach described in recently-declassified reports from the U.S.S.R., the U.S.A., and the U.K.

It is surely to be hoped that, as time goes on, it will be possible to broaden and strengthen this thin thread of cooperative effort in the fusion field. Certainly it would be difficult to find a field more aptly suited for international cooperation, for it is one of those rare programs that, because of its peacetime application and its vast technical potentialities, appeals to scientists and laymen alike throughout the world.

In spite of the formidable problems yet to be overcome, I am fully convinced that a power-producing thermonuclear reactor will be built

Whether or not it can ever be made economically competitive with other sources of energy—coal, petroleum, fission reactors—is anybody's guess at this time. It is, however, reasonable to expect that even if successful, this new source of energy will not displace any of the others, but rather supplement them during this era of rapidly expanding power requirements.

* This is not to say, however, that the controlled fusion reactor itself would be free from activity. The intense flux of neutrons produced in the fusion process will cause the surrounding structural material to become highly radioactive, and adequate shielding would be required.

Figure used by permission of Nuclear Development Corporation of America

reactor physics

By BERNARD I. SPINRAD

The reactor designer—once a physicist with a Marchant desk calculator—now feels lost without a UNIVAC and is eagerly making plans to use a super computer like STRETCH

REACTOR PHYSICS has only recently become an identifiable body of inquiry. Because the nuclear physicists invented reactors and explored their basic properties, reactor physics was, for a long time, considered a branch of nuclear physics. (In fact, work on the neutronic problems of reactors is still listed as nuclear physics by organizations such as the American Physical Society and the National Research Council's Roster of Scientific Personnel.)

However, in working with nuclear reactors, problems that arise are not really very close to those of nuclear physics but bear more resemblance to the problems of classical physics—the classical absorption and scattering of light, thermal diffusion, and chemical thermodynamics and kinetics. Also reactor physics necessarily involves a great deal of engineering. Nevertheless, the workers in reactor physics have formulated their field of applied science with reference to the common understanding of reactors rather than the individual design problems of separate systems.

By now the domain of the reactor physicist is fairly well defined. I think that most people in the field would agree in spirit at least with the following statement: Reactor physics is the study of the interaction of neutrons with bulk matter. It is particularly concerned with such interactions in systems containing fissionable materials. It encompasses the study of criticality of such systems and of the changes in criticality arising from mechanical, thermal, and radiation-induced changes in their properties.

In reactor design the engineering demand for exact reactor physics calculations seems to have been answered through the use of large computing machines. Ten years ago the typical computing device was the desk calculator; now the array of large machines available and commonly used is enormous. As recently as 1953, the acquisition of a UNIVAC by the Atomic Energy Commission was supposed to provide a facility which would saturate the demand for reactor computations; today virtually every major laboratory now has at least one and often a number of such complex computing devices as the IBM-704 or the UNIVAC Scientific.

The problems tackled by these machines are manifold. An excellent report by E. J. Leshan* points out that a typical computing center will have practically the entire contents of the Brookhaven cross-section compilation (BNL-325) available on input tape for use with a number of different reactor-physics machine programs. Included in the repertoire are calculations of thermal utilization and

* E. J. Leshan. Some reactor physics computing methods in use at American Standard, ASAE-20.

flux distribution by the P_3 and S_n methods, neutron transport by Monte Carlo, thermal motion of nuclei by the Wigner-Wilkins method, lifetime reactivity studies and steam boiling distributions in boiling reactors.

This is only one relatively small laboratory's program. In some of the exacting Naval and Air Force design problems two- and three-dimensional multigroup problems are repeatedly solved using a choice of slowing-down kernels and a variety of multigroup cross sections. Even these calculations are repeated to simulate detailed effects of burnup and control-rod motion.

However these computing devices are expensive to operate and it is improbable that a commercial designer could justify the cost of performing highly precise computation repeatedly during reactor design. Hence, the use of computing machines is becoming standardized to a point where the bulk work lies in solution of relatively simple calculations of limited precision. Such calculations are the one-dimensional multigroup codes, the multidimensional one-group codes, the one-group transport theory codes, etc. These codes are relatively easy to explain and have reached the point where nuclear engineers make routine use of them without the necessity of a physicist's intervention. The role of the physicist in such work has been reduced to that of providing the neutron cross-sections that serve as problem input.

The experimental areas of reactor design have also been developing in the direction of increasingly exact mockups of reactors being designed or operated. Thus, even Argonne National Laboratory, which has traditionally resisted this trend, is now conducting experiments on ZPR-III, which have the aim of mocking up the conditions of EBR-II as exactly as possible.

The field of reactor dynamics (the study of time-dependent reactor performance) is burgeoning, with increased emphasis on exact experiments and analyses bearing on reactor safety. Good examples are: The SPERT and KEWB experiments on heterogeneous and homogeneous water-moderated reactors. These experiments will help predict the results of quite drastic accidents such as loss of coolant, rapid removal of control, and the like.

Much use of computing machines is also made in the analysis of nuclear excursions, the gamut of methods previously described being supplemented by incorporation of the time-dependent reactor equations. Where effects are not believed to be predictable by analysis or where a check is required, reactor oscillation experiments and excursion tests are performed. It was during such a series that the EBR-I meltdown occurred and this meltdown has, in itself, pointed the way to a whole new set of analyses and experiments bearing on the problem of fuel meltdown.

While reactor design gets more detailed, reactor physics gets more comprehensive and more precise

Within the domain of reactor statics (the study of reactor behavior at steady state) the theorists are putting the computing machines to good use on many of the traditional problems of reactor physics. Thermal and fast neutron spectra have been mapped within the limits of input data; the vagaries of neutron-transport theory have been thoroughly explored; the exact behavior of resonance neutrons in the lower levels have been computed; and slowing-down distributions, based only on cross-section data, are available. Meanwhile, there is now a considerable emphasis on the performance of experiments that measure particular reactor effects in the absence of the complicating factors usually present in critical experiments.

These theoretical and experimental studies are the bases of reactor "integral theory and experiment" which is at the core of most conceptual reactor thinking. The integral approach, which relies upon bulk measurements as the raw material for reactor theory, has continued to be popular even in the face of competition from the exact neutron measurements and detailed computations of the Monte Carlo or multigroup sort.

Within the next 10 years common design problems will become increasingly the domain of fast computing machines and be run off under direct supervision of nuclear engineers

It is further predictable that theory will not provide the ultimate in the way of detailed answers. Because of unavoidable discrepancies between crude computation and observation and because detailed computations, while possible, are neither inexpensive nor definitive, experimental results will be called upon at earlier and earlier stages in reactor design. Ultimately, the present role of the theorist as detailed designer will probably be taken over by experimental physicists.

What is implied here is an increasingly empirical approach to detailed reactor design. Instead of attempting to calculate thermal fluxes in fuel elements of complex shape, they will be measured in a mock-up. Instead of guessing at plutonium reactivity effects, these, too, will be measured. Instead of making design modifications as a result of analytical perturbation of critical tests, the experimental physicist who has "played" with his critical experiment will be the proposer of the change. Moreover, this sort of experimental work will never become routine, to the point where it can be considered as a tool of engineering; the reverse, in which the experimental physicist is his own analyst and engineer, is becoming more common.

Bernard I. Spinrad

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I expect, therefore, that, insofar as theoretical physics is concerned with reactor design, its primary role will be in the more qualitative aspects. The integral concepts that were developed in the pre-computing-machine days will continue to be explored by the theorists. They are measurable, explainable on a simple and logical basis, and provide a much better background for intuition than do repetitive computations. Since qualitative arguments form the basis of new ideas, the theoretical reactor physicist will in the future, as now, be the chief inventor of radically new reactors. The reactor theorist will also be in demand as a critic, because his qualitative judgement will provide a quick check of calculations.

Within the framework of integral reactor physics, the central problem is to understand the various factors involved in criticality: fast and epithermal capture and fission; slowing down and thermalization; neutron-flux distributions and migration; and the interaction of these factors with each other. In these subjects, the correlation of exact theory with macroscopic effect and the accumulation of significant experimental data at the macroscopic level will deliver most of reactor statics in the form of organized models by the end of the next decade.

A good example may be made in the case of resonance capture. There are now several competing models for the process, based on formulations originated by Wigner, Dancoff, Pomeranchouk, and Galanin. Work now in progress has demonstrated that a more comprehensive picture can be achieved, in which each of the present models is a special case. This picture will undoubtedly be completely filled in within a decade.

New concepts in reactor physics and new reactor types go hand in hand

The half-fast reactor, the convergeatron, the two-sided Argonaut, and several advanced test reactors have had their origin in and focused attention on the physics of coupled subcritical systems (i.e., reactors in which criticality is shared between two or more radically different regions). New high-flux systems focus attention on xenon instabilities, burnup of short-lived fission products, production of high-order isotopes, and flux trapping. Propulsion systems, boiling reactors, and high-temperature reactors are connected with streaming problems in gaps and voids. Special research devices pose unique problems of such diverse sorts as the analysis of neutron fluctuations and slowing down at cryogenic temperatures. Fast and intermediate reactors demand slowing-down and spectral theories on the same level of simplicity as exists in the thermal-reactor field.

Reactor dynamics will still be a challenge to both designer and physicist for the foreseeable future

The problems arising in analysis of excursion, stability, and long-term reactivity trends are full of complexities, subtleties, and both physical and mathematical booby-traps. This field, which forms the body of reactor dynamics, has lagged behind reactor statics in progress. It is only now that we are approaching commercial operation of reactor plants; and in such systems, ease and safety of operation are far more significant problems than is the case in the remotely located production plants.

In addition, recycling of coolant in power plants ties the standard reactor-kinetic equations directly into power-plant cycle analysis. Since power plants are expensive, we cannot expect to obtain data from system mock-ups without simplifying the systems to the point where results may not be reliable. Two approaches will be tried:

The first is the analytical, in which those phenomena that are predictable (such as delayed neutrons, coolant-circuit times, heat-removal laws, control-rod motion, power demand, and so on) are synthesized into a set of mathematical equations whose solution is determined from initial conditions. Obviously connected with this approach is the procurement of decent physical data as input for the required calculations.

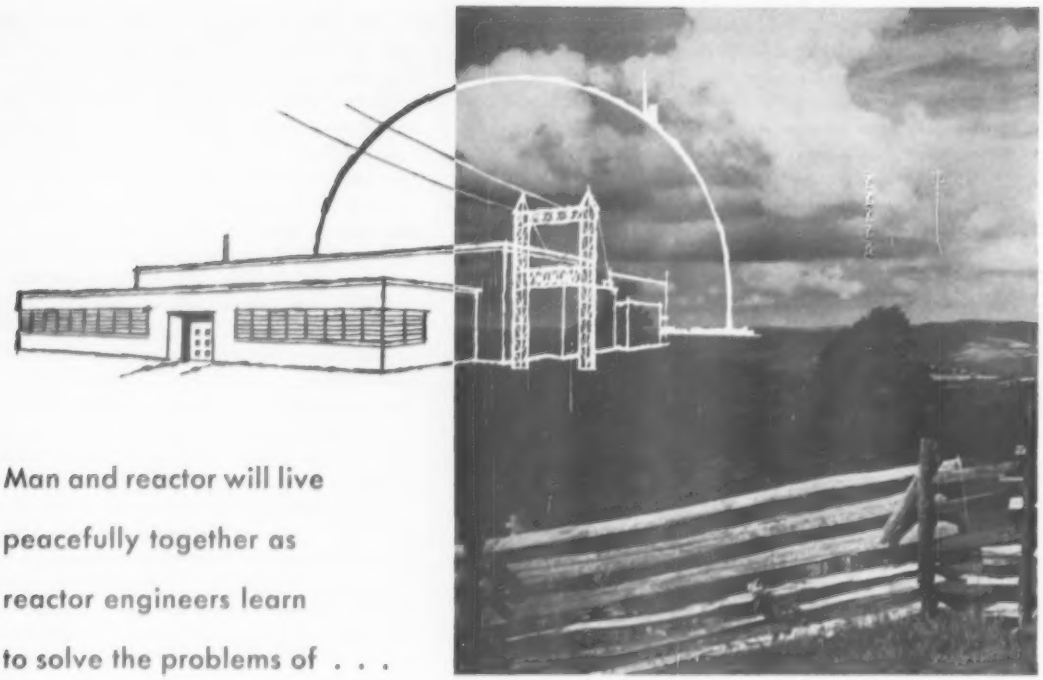
The second approach is through the use of operating test reactors. Such systems as the BORAX reactors, which have given us gross operating features of a typical boiling reactor, are examples. These reactors cannot, of course, tell us the details of reactor dynamics. Rather, they can map out ranges of variation in design and operation within which stable operation can be assumed. In this way, general patterns of dynamic behavior of reactors may show up more clearly than by the analytic method.

The two efforts are, of course, capable of correlation. I do not think, however, that this correlation will result in an integral theory of reactor dynamics, although several have been attempted. Rather, the correlation will be in terms of rules for reactor design and operation that are similar to the rules of strategy in chess—of great power but subject to exceptions and restrictions.

Heat transfer will be the subject of fundamental reinvestigation as reactor designers strive to achieve high power densities

Another prediction can be made on the basis of need rather than history. The intrinsic worth of nuclear fuel is as a compact source of energy, and its use in many applications requires rates of heat removal that are not standard in engineering practice. These heat transport problems—burnout, film blocking, instigation of boiling, channel circulation—and their accompanying chemical effects are now in the competent hands of heat engineers. However, it is becoming clear that these problems would be enormously simplified if physical laws could be found to supplement and extend the existing correlations. Fluid dynamics and thermodynamics are, it is true, subjects that lost their popularity in physics forty years ago; but they are still within the scope of physics and, in fact, many nuclear models have their basis in this field. Hence, as the need grows, I predict that reactor physicists will be progressively involved with groups doing research on fluid and thermal dynamics.

As a final prediction, the next ten years will see reactor physicists making significant contributions in thermonuclear energy, many problems of which are remarkably similar to those arising in fission systems.



Man and reactor will live peacefully together as reactor engineers learn to solve the problems of . . .

reactor safety

IT BECAME CLEAR in 1954, with the passage of the revised Atomic Energy Act, that Congress, especially the Joint Committee on Atomic Energy, was fully aware of the necessity for guarding the public health and safety in the utilization of atomic energy. The interest of Congress in this field has increased rather than decreased since the passage of that legislation.

The public too has become increasingly aware of atomic energy and its byproducts, as is evidenced by the widespread discussion of "fallout" and the headlines that have resulted from minor accidents with radioisotopes.

On the other hand, the public has shown relatively little concern about reactors, presumably because comparatively few are operating and are doing so with an excellent safety record. The current intervention by unions in the case of the Power Reactor Development Company construction permit was based only partly on the safety question.

Since its formation, the Atomic Energy Commission has been concerned with the reactor safety problem. It first set up the Reactor Safeguard Committee, then the Industrial Committee on Reactor Location Problems, and now the Advisory Committee on Reactor Safeguards. AEC has established a technical staff to deal with the evaluation of reactor hazards. It has sponsored the development of more reliable and safer reactors and has invested and is investing large sums in research on the many unsolved problems related to reactor safety.

Regulations are in effect now requiring a complete description of proposed reactors, their site, and proposed operation. The regulations also require that the applicant make a study of the possible and probable accidents and show that all reasonable precautions have been taken to protect the public and employees. All applications, including the applicant's hazards summary report, are available to the public as are the evaluations and actions of the AEC.

Before describing the problems that lie ahead, I would like to enumerate the facilities in existence or proposed. In the field of privately owned reactors or others subject to licensing, there is one critical facility operating and 6 more in the construction-permit stage; 21 low-power and 6 moderate-power research reactors operating and 3 more in the construction-permit stage; two testing reactors with construction permits; and 4 power reactors with construction permits.

Under the jurisdiction of AEC and other government agencies, numerous critical facilities are operating, several research reactors, one testing reactor and another about ready (MTR and ETR, respectively), and 5 power reactors (APPR, EBWR, Nautilus, Seawolf, and SRE), and

By C. ROGERS McCULLOUGH

the PWR is expected to start up in a very few months.

Although critical experiments are more prone to accident than other reactors, it is comparatively easy to protect the public and employees from injury and to avoid public damage, and there is experience to go on. However, with reactors of substantial power level, there is a large potential hazard because of the accumulation of fission products. The range of damages expected is described in a recent report.* Under very bad conditions large numbers of people could be killed or injured and billions of dollars of damage caused.

Worries will begin as power and test reactors are ready to operate.

Up to the present, privately owned research reactors have been limited to 5 Mw or less. The proposed power levels of forthcoming test and power reactors will range from 20 to 500 Mw and above. That will be more serious from a hazards view.

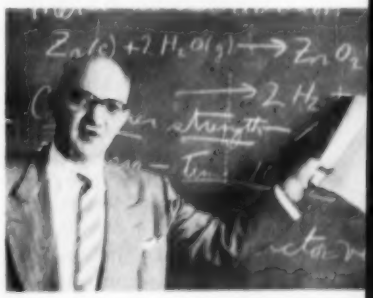
The safety record of *regularly* operating reactors has been phenomenal—perfect. There have been a few accidents during *non-normal* operations. This record is due to the careful construction of the reactors, the skill of the organizations operating them and perhaps, to some extent, good luck.

In the period ahead, reactors may be built by organizations with less skill and tighter dollar and manpower budgets.

During the early period it was customary for the reactors to be operated by those building them. The machines were their brainchildren. Increasingly in the years to come reactors will be built by equipment manufacturers and operated by entirely separate groups. Some of the future operating groups will be quite new to the business. How does one make sure that they will adequately understand the reactors they will be responsible for? The individual skilled attention required to design and evaluate reactors makes heavy demands on the available skilled manpower.

Reactors of substantial power are not yet standardized—it is well they are not in this early stage of the technology. Yet this highly desirable variation makes it difficult to evaluate the different reactors. These machines have certain subtle characteristics that can cause serious troubles if some autocatalytic or oscillatory characteristic creeps in. This is the prime reason that hazard evaluation is today a matter for skilled attention to each individual reactor. It is necessary to preserve an open and alert mind in studying the varied types of reactors and the variations within the types. There is much to be said for and against the safety of all the reactors, and there is not yet a perfectly safe one.

It is the proper attitude toward reactor reliability and safety for adequate protection of employees and the public that is one of the most important problems of the industry today. With the concern the public has today about the harmful effects of radioactivity, a serious reactor accident could set the industry back many years. On the other hand excessive caution, lack of recognition of the essentials of reliable and safe reactor design and operation, could result in overloading reactor facilities with unnecessary and expensive devices and safeguards. This too could set the industry back. It is very difficult to recognize those features of a reactor that are essential to safety and



C. R. McCullough

Deputy Director for Hazards Evaluation, Division of Civilian Applications, Atomic Energy Commission and Chairman of AEC's Advisory Committee on Reactor Safeguards.

* Theoretical possibilities and consequences of major accidents in large nuclear power plants. Report by AEC, March, 1957.

to design so as to emphasize those features without too great a sacrifice in other features and cost.

There needs to be better understanding of the features that are essential to safety.

A discussion of the unknowns in reactor safety could be lengthy indeed. To start, the nuclear properties of reactor cores are not fully understood and the valid data are largely empirical. Calculations are complex and almost always contain constants that make the calculations fit the facts. The calculations of critical masses often miss the actual value by as much as 20% and more. Localized effects are very difficult to estimate accurately. Sometimes one cannot predict the sign of a power, temperature or void coefficient. The transient and shut-down behavior of swimming pool reactors cannot be satisfactorily described although qualitatively it is understood. Transient behavior in general, including transient heat transfer, and oscillatory effects, needs to be studied much more by theory and by experiments. A better knowledge is needed of the actual temperature rises that might be experienced in a reactor core in case coolant is lost.

The standards for materials and equipment for nuclear plants are necessarily higher than those now accepted by industry. A better understanding of the properties of steels and other metals under stress, whether transient or steady or caused by pressure, temperature, shock, etc., is required. More reliable methods of inspection and means of interpreting the results are needed.

How does one inspect a reactor vessel after it has been in service?

The knowledge of corrosion and fatigue needs extending. Most of all one needs to have a quantitative knowledge of the effect of various forms of radiation on the properties of materials which may be used in reactor construction.

There still remains the ugly question of the reaction of water, a most useful reactor material, with aluminum, zirconium, uranium, thorium, etc. Under what conditions will this reaction occur? When will it become violent? What fraction of the core is likely to react?

What about radiation release? It has been demonstrated that reactors can be operated with release of radiation so small as to be comparable with radiation from natural sources. But the fact remains that much more knowledge is required on the effect of the various forms of radiation on health, longevity, and heredity. It is already well recognized that various radioisotopes vary widely as to toxicity. Economical means of separating and disposing of the more dangerous radioisotopes need to be developed.

Finally in case the unfortunate and improbable major reactor accident occurs there must be: ways of balancing the possible injury and cost of evacuation versus exposure to radiation; methods of decontaminating large areas, cities, etc.; and means for preventing future injury to people from the deposition of dangerous radioisotopes like plutonium and strontium-90.

Without question there is a large amount of theoretical and experimental work yet to be done.

The release of fission products from the present design of reactors can be caused by nuclear transients in which the generation of heat can outstrip any conceivable cooling means. The other means of release can be the melting or even vaporization of the fuel because of the loss of coolant even with the nuclear reaction shut down. One obvious solution is to remove the fission products relatively soon after they are formed and store them in some place where they are safe from accidental release. It is not necessary to remove all of the fission products but only those contributing the greatest hazard.

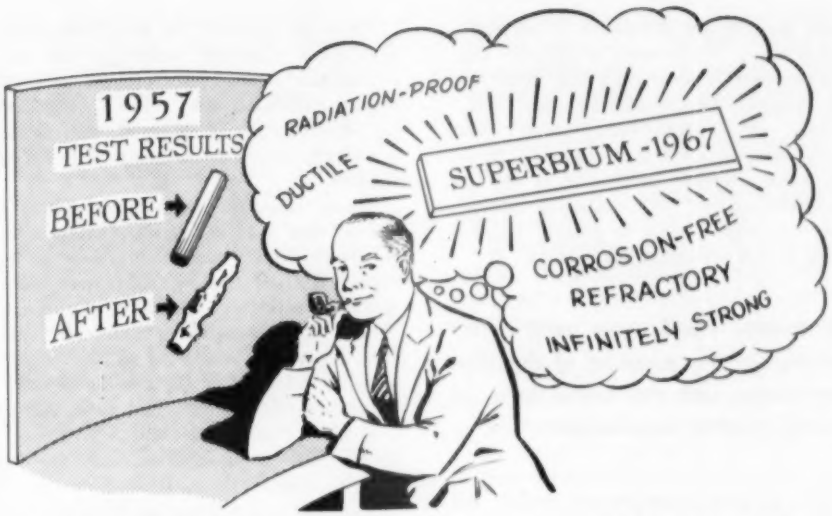
One would hope for reactor designs of inherent safety so that dangerous transients are not reasonably possible. Such reactors if either of low enough specific power or with really fail-safe cooling systems can probably be fully automatic in operation. One can imagine a sealed-package type of reactor that can either be automatic in operation or require only unskilled operators. Only maintenance would require persons skilled in the technology. To bring this about requires the theoretical and experimental work mentioned previously and the demonstration of the actual reliability and safety by full-scale operation and testing of such machines.

The future holds safer reactors, yet there will be more emphasis on government regulation and industry standardization.

There will be a recognition by the atomic energy industry that true progress requires the development of increasingly reliable and safe reactors. There will be developed reactors with inherent stability against nuclear transients. Cooling systems will be devised which can be considered truly reliable. On the other hand, means of containing reactors will be devised so that even if the machines are destroyed one is assured that employees and public are protected. New concepts will be developed. The newer reactors will be more economical than present designs.

The discussion of weapons effects and "fallout" and the worries of the geneticist have set the ideas of the public in a conservative channel. There will be questioning of the reliability of reactors. The public will want to know that their health and safety will be looked after, perhaps even to the extent of impeding progress somewhat. There will be a trend to more government regulation rather than less. The state governments will extend their regulatory activities affecting the industry, and federal regulation will be made stricter. Several standards can be expected to be adopted within the next decade.

The professional men and the industries engaged in atomic energy must get together and set up objectives and standards for the economical and safe design, construction, and operation of reactors. Such groups must function with a positive attitude—standards must be set for progress. They must take the lead in encouraging new concepts and new approaches. At the same time they must police the industry when it is needed. This group must cooperate with the government. The government must regulate the industry only to the very minimum required to protect the health and safety of the public. The regulations should be simple and the processing of cases should be rapid and efficient. With a strong professional and industrial team working with an efficient government group there can be progress toward standards for a safe atomic energy industry.



FACED BY LIMITATIONS of today's materials, reactor designer dreams of what 1967 may bring

reactor materials

By D. O. LEESER

THE SIGNIFICANT TECHNOLOGICAL advances made in the nuclear-energy field during the past 10 years have occurred in materials technology—chemistry, metallurgy, ceramics and radiation effects.

During the next 10 years, we will find the designer specifying more stringent conditions requiring better thermal, radiation and corrosion stability. These problems and approaches to their solution are discussed here.

The term "radiation damage," as applied to structural metals, is rapidly being superseded by "radiation stability." We are acquiring a basic understanding of radiation effects to the extent that an adequate selection of materials will be available for specific applications. The theories of radiation effects in solids are not, as yet, satisfactory.

Science has come a long way, not only in understanding, but in practical results. Neutron irradiation does not result in a severe increase in creep rate at lower fluxes, as was earlier supposed. In heavily cold-worked metal samples, neutrons may produce effects similar to an annealing heat treatment, indicating that it is not completely analogous to cold work. While more recent studies suggest a resemblance to solute hardening, the magnitude of property changes is too great to confirm this suggestion. For solid-state processes in which diffusion is the primary mechanism, the effect of neutron radiation is equivalent to an increase in temperature.

Apparently, the initial state of a material has an effect on the radiation-induced changes. Further fundamental work should be initiated to determine whether there is a composition effect due to certain impurities, and whether heat treatment or other metallurgical practices have effects on radiation stability. From a fundamental standpoint, it is obvious that additional work is also needed to distinguish between the effects caused by fast flux, exposure time and irradiation temperature. It will also be necessary to establish the lower limits of ductility loss and/or embrittlement and to determine whether the apparent effect of saturation is a true picture.

Another important area that requires considerable investigation for basic understanding is the effect of radiation on precipitation-hardening alloys, particularly those that are used in industrial applications. The combined effect of irradiation and temperature aging should be separated, and the effect of precipitate particle size should be included in this investigation. The causes of resolution-precipitated particles and evidence for resolution or homogenization by neutron irradiation should be confirmed.

Because of the present sparsity of data, interpretation of radiation-effects data is a difficult task for the design engineer. As more and more data is compiled, the interpretation—not the data itself—is becoming the more important consideration.

Structural metals usually are evaluated by strength, ductility and impact tests. An increase in strength usually is regarded as beneficial if there is no concurrent loss in ductility, which normally decreases after neutron irradiation except perhaps at elevated temperatures. The difficult problem has been, and will continue to be, to set limits on the allowable decrease because it is not yet possible to assess quantitatively the meaning of ductility values. Radiation has been known to reduce ductility below the minimum ASTM specifications.

The next decade should give us a better understanding of the meaning of ductility, its interpretation and the lower limits of ductility within safety requirements.

The fatigue properties in reactor pressure vessels will continue to be a major factor because of the thermal-stress conditions and possibly the thermal-shock conditions during startup, shutdown and reactor transients.

Many untried materials will be irradiated, and experimenters should include with their specimens suitable fast-flux monitors so that the results on exposed materials can be directly compared with other data available. One of the difficulties in comparing and evaluating the results has been that many exposures have been reported in terms of thermal-neutron exposure or simply by the length of exposure in the reactor. Design evaluation requires an accurate analysis of the exposure.

One important benefit expected from the use of power reactors, which are going to operate at higher temperature and higher power, is that the increased temperature may anneal out many of the radiation effects. However, caution should be used in accepting this prediction since increased irradiation temperature does not always result in a lesser change than at lower temperatures; the ultimate strength of carbon steel may show greater increases at higher irradiation temperatures, although the amount of increase in yield stress is reduced by higher irradiation temperatures. Certain materials, such as plastics, which do not normally operate under high temperature conditions, cannot be expected to be benefited by high-temperature conditions.

David O. Leeser

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When the question of flux dependence arises in the absence of a suitable theory, it has been necessary to extrapolate beyond our present knowledge and again take a calculated risk. Hence, it is desirable to build high-flux reactors in as simple and as safe a fashion as possible to obtain the necessary data for subsequent plant designs.

Many industrial materials exhibiting poor results in special tests need not be disqualified as inferior products for reactor use. Slight variations in composition and adjustments of binders, plasticizers, pigments, etc., are known in many cases to affect their properties.

It is not inconceivable that many chemical materials that have been discarded as not having the radiation stability expected of them under certain conditions will be adjusted for use in limited areas, perhaps as protective coatings. Furane-base and epoxy-base coatings have shown excellent chemical resistance and decontaminability after exposure to the radiation from spent fuel elements.

The use of inhibitors or "protectors" to reduce the ionizing effect of radiation on organic lubricants will probably be accelerated. In a short time we will probably see use of certain lubricants that are today considered ineffective because of breakdown under irradiation.

The radiation resistance of a given electronic component varies widely from manufacturer to manufacturer. There is hope that only minor changes in materials and designs will greatly improve many components. Tests on resistors, semiconductor devices and vacuum tubes support this view and indicate that the less complex and less sensitive electronic components are not so affected by irradiation. It has also been indicated that gas evolution in vacuum tubes under irradiation can be solved by studying seals and glasses.

Far too little is known about the behavior of materials in high-temperature reactors. We have been designing structures using test data that very seldom resemble the anticipated service conditions. As a result, in many cases we are forced to use an unreasonable "safety factor" that is actually no more than an "ignorance factor." Materials usually perform satisfactorily if they are maintained continuously at high temperatures but may fail because of thermal shock due to rapid cooling or heating.

The behavior and properties of stainless steels at elevated temperatures are under continuous review. As new data are acquired and as the accuracy of stress analysis improves, the allowable stresses are changed in ASME codes. More often than not, the high-temperature tests on which these allowable stresses are based are only of 1,000-hr duration, extrapolated for as much as 300,000 hr. More data are required to evaluate materials for the service time to which they will be subjected in operation.

Ductile refractory coatings have been under investigation for use at high temperatures and under thermal-shock conditions. To date most coatings have been developed to resist chemical, mechanical or electrical stresses at moderate temperatures rather than to contain heat. The reason is that the low thermal conductivity of some refractories is more effective as a brick than it is as a coating. The higher the temperature of application, the greater is the potential temperature gradient in the coating, and the more valuable even a very thin coating may be because of the relatively low absorptivities and conductivities of

ceramic materials. When prolonged exposure to heat is involved, the coating must be thicker and increased coating thickness introduces additional problems. For example, the differences of thermal expansivity between coating and base material are magnified at high temperature. Moreover, the thick coating itself begins to show a tendency to embrittle, which is characteristic of refractory bodies.

Nuclear-source temperatures of 2,000° K will be attained within the next few years under static conditions in reactor experiments. Techniques of arc discharge and exploding wires have produced temperatures in excess of 10,000° K in impulses. To contain reactions to these temperatures, even temporarily, materials must be developed that will not react in the high-temperature environment. A prerequisite might be to avoid any unnecessary impurities in the high-temperature region.

Compatibility of structural materials with the selected coolant is a prerequisite for use of these materials. Although an impressive amount of data has been assembled on heat transfer, convective flow, thermal stress, thermal shock and other phenomena important to the use of materials in coolant media, it is still difficult to translate these effects directly to an operating system. The mechanism of corrosion is basically different for liquid metals than for water or for gases, and we are just learning how to specify a practical system with confidence.

The trend in recent years has been to avoid the "exotic" materials. Except for the containment of aggressive corrodents, such as fused hydroxides and molten plutonium or uranium, there has been a tendency to go from the austenitic stainless steels to the less expensive, low-alloy, low-carbon steels used in conventional power plants.

The trend toward less exotic materials will continue for systems whose temperature ranges do not exceed 1,100° F.

Above these temperatures, the higher-strength materials, such as the higher alloys, must be used.

Increasing the alloy content of the material is not necessarily the answer. As a rule, when a material is protected against general corrosion, it becomes more susceptible to such insidious attack as stress-corrosion cracking, knife-line attack, phase-precipitation embrittlement, etc.

The progress made in handling liquid metals is an example of successful materials technology. The alkali liquid metals, as well as others such as bismuth and lead-bismuth alloys, have superior heat-transfer properties compared with pressurized water or gas. Initially, however, it seemed that corrosion would prevent the use of these liquid metals. By painstaking removal of certain impurities, these liquid metals can be contained at high temperatures for extremely long periods.

For some reason or another, standard fabricating practices have not proved successful when applied to special materials. The apparently simple operation of putting a protective aluminum can around uranium slugs turned out to be one of the most difficult single technical problems encountered in this new field. Entirely new standards of reliability were found necessary, and, while many highly refined techniques were discovered, no new basic technology was acquired.

During the last decade we have learned much about the rare earths—how to produce them in larger quantities, in higher purities and at lower cost. Many have high neutron cross sections and thus can be used in control or shim rods. For use in thermal reactors, gadolinium has been suggested instead of cadmium, but even gadolinium may be replaced by europium. An excellent use for cerium, for example, is as an additive to glass used for shielding personnel from gamma radiation.

However, several scarce metals suffer from a vicious cycle. There is little demand for them probably because their price is excessive and their properties have not been sufficiently determined to create specific applications.

Much attention has been given powder metallurgy. One of the most recent developments in this field is the production of fibrous metal. Techniques have been evolved to produce powder metal in long fibers with strength of the metal running the length of the fiber. Other areas of powder-metallurgy are being explored, such as the mixing of low-melting and high-melting metals, which would be difficult under ordinary melting processes.

Binders for joining large sections of such brittle materials as graphite, borated graphite and tungsten should come under careful scrutiny. The innoculation of large amounts of boron carbide or ferro-boron into such common materials as graphite, plain carbon steels, or possibly even organic materials is imminent.

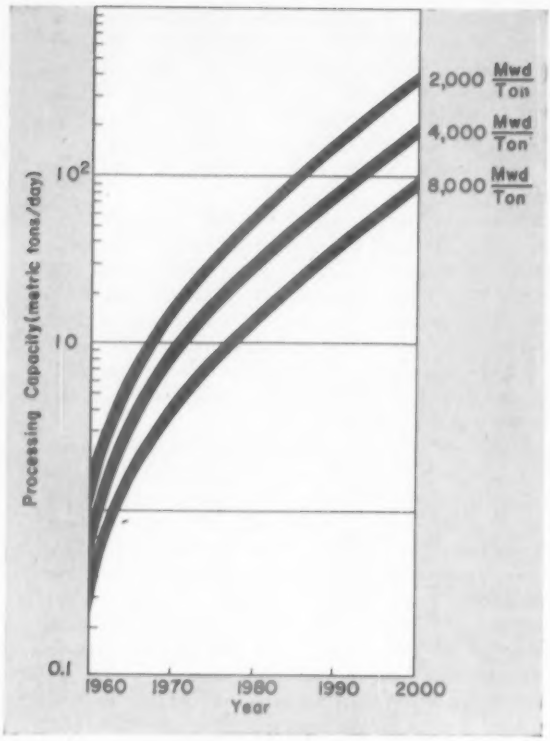
Increasingly severe conditions of speed, load, temperature and corrosive atmospheres have placed new demands on load-bearing materials. New materials for contact surfaces and separators are coming under careful scrutiny to meet these new developments.

As the demands increase, it is not unreasonable to expect that the development of self-lubricating bearings will be successful even to the point of carrying high unit loads at elevated temperatures.

Conventional materials with the greatest promise for temperatures up to 900°–1,000° F are the high-speed tool steels, because they have good hot hardness, dimensional stability and high-temperature strength; however, tool steels contain excessive nonmetallic inclusions. Nonmagnetic materials are desirable for bearing applications where the magnetic properties of conventional materials may disturb equipment operation, or where an accidentally magnetized bearing may transmit a signal that would interfere with the expected operating signal.

Corrosion-resistant materials are required for operation in pressurized water at temperatures up to 700° F. Lubrication in liquid-metal-vapor environments or in inert gases at temperatures above 400° F generally is not possible. Nongalling and wear resistance are important under these conditions. Cobalt-base and chromium-base materials have been tried, often with good results, and at other times only a few minutes' total cyclic operation is expected.

Laboratory wear tests have been run on sintered materials such as tungsten carbides, chromium carbides, nickel borides in mixtures with nickel, and on glass, sapphire, graphite and cermets. Inherent brittleness is a common defect of these materials.



PROCESSING-CAPACITY requirements for predicted nuclear-power economy (based on installed nuclear power plant generating capacity predicted by J. A. Lane, NU, Oct. '54, p. 65).—Curve provided by Floyd L. Culler, Jr., Director, Chemical Technology Div., Oak Ridge National Laboratory

chemical reprocessing

By S. LAWROSKI

A NUMBER OF ESTIMATES have been made of the probable processing load that will be contributed by the various military propulsion and civilian power reactors.

It seems certain that existing plants can, if desired, handle all expected loads for the first half of the decade (until 1962) and that additional plant capacity may be needed during the second half. It now appears that the additional facilities would incorporate solvent extraction. Not until late in the decade is it expected that plants based on other separations methods will be considered.

It is doubtful that private industry will immediately enter the reprocessing field at currently suggested prices for recovery of reactor fuels. Major deterrents are insufficient feed loads and excessive variety of feeds. To allow profitable operation and adequate investment return on processing plants, it will be necessary to have more standardization of fuels and a very substantial number of operating reactors.

Recognition is finally being given to the interdependence of fuel reprocessing, fuel fabrication and reactor operation in the optimum reactor fuel cycle. The next decade will see increased emphasis in this regard so that close cooperation among process designers, fuel technologists and reactor designers will thus be the rule rather than the exception.

Work will certainly continue in conjunction with existing solvent-extraction plants to improve the present processes. Much progress has been made recently, and may be expected to continue, on the reduction of waste volumes by the reuse of reagents and the back-cycling of waste streams. Improvements in the operations of contactors may be expected to reduce carryover of activity and may lead to the elimination of one or more extraction cycles. Because of solvent damage by radiation, there will be increased interest in contactors that minimize residence time.

The present assault upon the conversion of purified uranyl nitrate to uranium tetrafluoride may reasonably be expected to give improved throughputs together with decreased cost.

By the end of the decade, most UF_4 will probably be made on a continuous basis in moving-bed or fluid-bed systems

It is possible, but not likely, that entirely new solvents may be put into use. If a solvent significantly more

radiation-stable than those now used were found, there would be considerable incentive to make use of it.

Much of the development work in connection with solvent extraction will be directed toward devising "head-end" treatments for the more "exotic" fuel assemblies (stainless steel, oxides and ceramics—some of these like stainless steel are not ordinarily intended to dissolve) that will permit their dissolution and compatible introduction into existing solvent-extraction plants. For most of these fuels, technically acceptable "head-end" processes should be devised. Whether or not these procedures will lead to acceptable economics is not yet clear.

At the present time, active development work is being pursued on two major alternate types of processes—volatility and pyrometallurgical processes. The dividing line between these processes is somewhat diffuse, but the former involve the use of a fluoride system and the production of uranium hexafluoride while the latter involve higher temperatures and generally maintain the chemical integrity of the fuel during processing.

Several volatility processes have been brought to the pilot-plant stage, but as yet no plant has been put into the program. This type of process appears marginal for application to low-enrichment, low-alloy fuels. Within a year a clear-cut decision will likely be made as to the value of continuing work on this particular type of fuel. For highly enriched and highly alloyed fuels there appears to be considerable promise for this type of process. It is expected that during this coming decade one or more volatility processes for highly enriched fuels will be thoroughly tested at the pilot-plant scale, and, in the latter part of the decade, at least an experimental plant built.

Volatility processes also have application to homogeneous reactors of the liquid-metal-fuel-reactor (LMFR) type. It seems clear that development work on processes for liquid-metal fuels will be carried out, and, depending on the success of this work—and of the LMFR itself—a volatility plant of this type may be built.

Pyrometallurgical development work has so far been carried out largely in connection with the LMFR, SRE and EBR-II projects. Early in the decade an experimental plant will be built in conjunction with one or more of these reactors.

If, as is expected, pyrometallurgical plants work well technically and if the economics are as favorable as is hoped, by the end of the decade pyrometallurgical processes are likely to become a serious competitor to solvent extraction

At the present time only two pyrometallurgical-type processes are being exploited on an intensive engineering scale—oxide drossing for core material and molten-metal extraction for blanket material. A wide range of additional development work is contemplated, however, and processes that make use of a lower-melting metal solvent (e.g., zinc or mercury) appear quite promising and versatile and may eventually replace oxide drossing.

It is unrealistic to assume that the current ideas are all that will be discovered. Almost certainly in ten years some entirely new approach will be suggested and become a part of this program.

The present development status of the mentioned alternate processes has already revealed the major obstacles to be construction-materials problems. Therefore the emphasis of development work on these processes during the next decade will be to correct this situation. If major break-throughs are realized in this regard, it is entirely possible that some of these processes would be promptly considered for new separations facilities because they are very likely to be more economic than solvent extraction for limited feed loads.

Progress in the waste-disposal field has been slow for the past several years. There are signs of a renaissance at present, however.

The highly successful efforts to reduce process-waste volumes in existing plants have already been mentioned. This laudable work reduces the magnitude, but not the essential character, of the problem.

In an effort to find a more satisfactory long-term solution to the problem of storage than tankage, there are at least five major projects at present seeking ways to immobilize wastes as more or less nonleachable solids. All of these show promise. It seems highly likely that during this decade several ways to immobilize wastes satisfactorily will be developed.

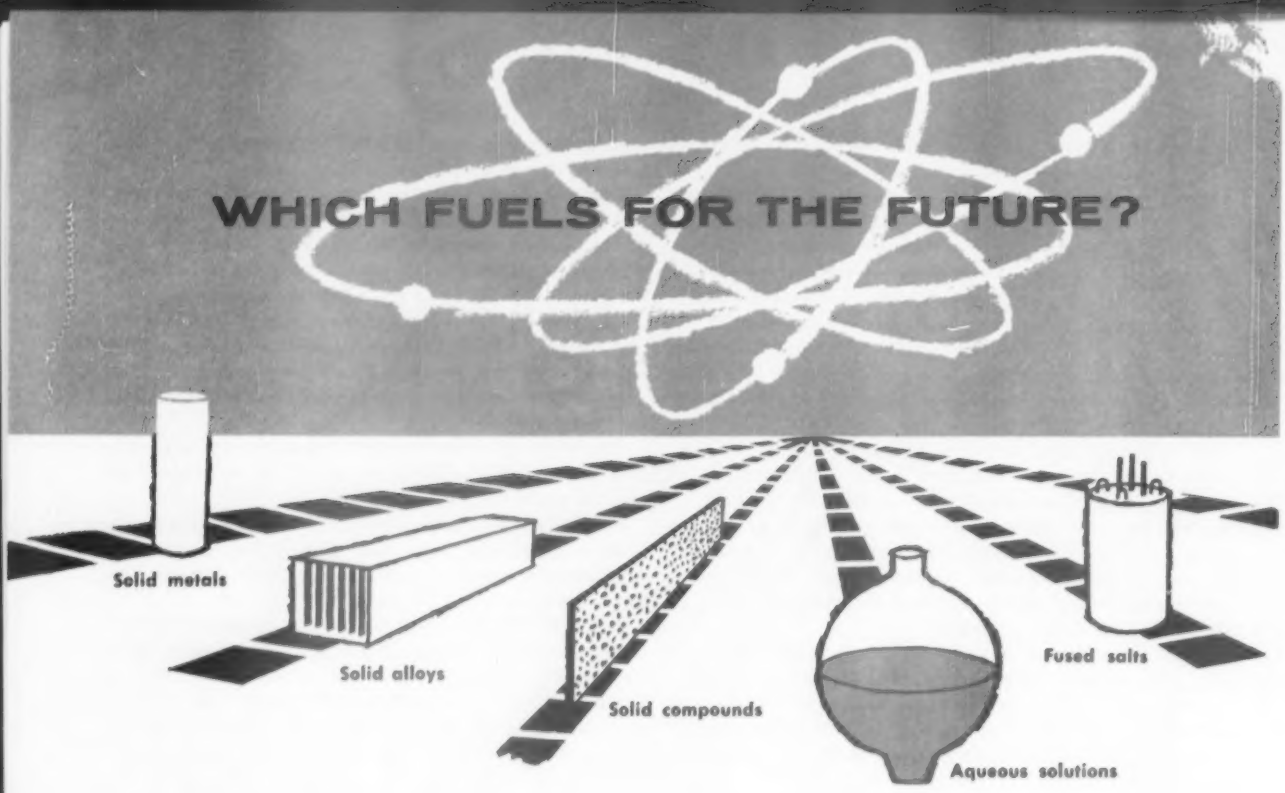
It is also expected that considerable progress will be made in determining the extent to which significant quantities of waste may be discharged to the environment such that final control is lost. Already the British are determining the levels to which coastal sea waters may be used.

During the next ten years, significant experimentation on the use of ocean deeps and deep wells may be started. However, the interpretation of results will take many years

Finally it is hoped that some progress will be made toward selection and acceptance of ultimate storage methods. Here, again, the problem cannot be solved within the decade since evaluation of storage methods acceptable for centuries can hardly be made in a decade.

Stephen Lawroski

Director, Chemical Engineering Division, Argonne National Laboratory since 1947.



reactor fuels

By A. R. KAUFMANN

A NUCLEAR FUEL may be defined as any material containing fissionable isotopes. Because a complete discussion of nuclear fuels would encompass too broad a subject area for the space allotted, certain limitations must be imposed. This discussion, therefore, will be confined to the physical and chemical properties of nuclear fuels and will be further limited to those fuel materials that seem to have practical application.

The fuel materials that seem to have practical application can be considered under two broad categories, according to their physical state, namely, solid or liquid. They can be further divided, under these two headings, according to their chemical state, namely, free metal, alloy, or compound. Regardless of category, however, each fuel material must be judged according to criteria of desirable characteristics. Before discussing fuel materials in each category, therefore, it will be well to set down the requirements of all nuclear fuels as viewed in the light of certain known phenomena.

Fuel requirements. Materials to be used as nuclear fuels are required to have suitable nuclear properties, to be capable of preserving their chemical and physical properties, to have dimensional stability, and to be corrosion resistant. The desirable characteristics of any nuclear fuel, along with a number of general observations as to their behavior, are discussed here to focus the subsequent discussions of particular fuel materials.

Suitable nuclear properties. This applies to the fissionable atoms, the diluent material, and the cladding. The reactor designer sets the initial conditions and is concerned with how they change with burnup. One of the phenomena of the behavior of fuel materials is the buildup of fission products. The harmful effects of these "foreign" atoms becomes more apparent as burnup progresses.

Preservation of properties. The chemical and physical properties of nuclear fuels should be preserved during use. Three known phenomena tend to prevent this. These are:

(a) Crystal lattice distortion. High-energy particles can displace atoms in a crystal. In metals this phenomenon leads to increased hardness and strength and decreased ductility and thermal conductivity. Present information, however, indicates that these changes are not large enough to impair seriously the use of these metals.

(b) Phase changes. High-temperature allotropic forms have been observed to appear in some uranium alloys and

Liquid metals

in certain compounds as a result of irradiation. The initial properties of the fuel material may be altered by this process, but the effects need not be harmful provided that they are anticipated and allowances made for them.

(c) Chemical bond changes. Chemical bonds can be broken by high-energy particles. It appears, however, that decomposition in ionic compounds does not reach serious proportions in present reactors.

Dimensional stability. Nuclear fuels should have dimensional stability to permit well defined flow of coolant and to avoid unexpected changes in reactivity. This desirable characteristic must be viewed in the light of two known phenomena. These are:

(a) Creep under irradiation. Present evidence indicates that creep under stress is not increased by the bombardment of heavy particles and may actually be decreased. This is important because it means that solid fuels can support the same stresses inside a reactor as under ordinary conditions.

(b) Rare-gas fission-product buildup. The rare-gas fission products, which will not unite with other atoms in the fuel, are sources of concern in this area. The situation is not well understood, but it appears that trouble may be expected, at least in the free metal uranium, when the number of fission product atoms reaches about 1% of the total number of atoms. Operation at high temperatures will aggravate the buildup of stresses in the fuel material.

Resistance to corrosion. Nuclear fuels should be corrosion resistant to prevent deterioration of the fuel and the subsequent spread of fission products throughout the system. The resistance to corrosion of the meat is highly desirable regardless of the fact that the cladding gives primary protection. It seems reasonable to expect that irradiated fuels will corrode more readily than the original materials. Experience has shown that this effect is not particularly large in most cases. There is little indication that corrosion by water of uranium and its alloys is drastically altered by burnup. Water corrosion and oxidation of cladding are not appreciably altered by irradiation. The same is true of attack by liquid sodium. It has been reported, however, that corrosive attack by aqueous solutions of uranyl sulphate is increased during irradiation.

It is difficult, if not impossible, to provide a nuclear fuel that will have all these desirable characteristics. For this reason, most fuel materials represent a compromise of conflicting situations. The final choice of fuel material is determined by the requirements of the reactor system that seem most important to the designer. The following discussions will present pertinent facts about each category of fuel material and will comment on their future development.

Solid fuels. Those that seem to have practical application fall into three categories: (a) free metals such as uranium and plutonium; (b) alloys such as U-Al, U-Mo, and U-Nb; and (c) compounds such as UO_2.

Uranium. Solid uranium has been used as a fuel more extensively than any other material, and it appears that this will continue to be the case for some time. Early experience with the metal at temperatures below 300° C indicated that it would rupture at burnups as low as 0.05% and that this difficulty was increased by higher temperatures. It has been found that performance is greatly improved by the use of high-quality metal having a minimum of internal flaws (such as massive inclusions of oxides and carbides). Good metal operating at temperatures up to 400° C appears to be capable of at least 0.5% burnup.

Single crystals of uranium are deformed in an anisotropic manner by fission. In polycrystalline fuel elements having preferred orientation or coarse grains, this phenomenon can lead to extensive dimensional changes and surface roughness at relatively small burnups. Elements having fine grains and random orientation avoid these troubles. Fabrication of pure metal in the gamma phase leads to coarse grains, whereas fabrication in the alpha phase leads to preferred orientation. Rapid cooling from the beta phase tends to produce random orientation with moderately fine grains and, therefore, such treatment is widely used. It is expected that future developments aimed at producing cheaper fuel will uncover fabrication techniques

A. R. Kaufmann

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that will make the beta treatment unnecessary. This will be particularly important for processes which may produce a fully clad fuel element in one operation from the original ingot.

It seems doubtful that cast natural uranium will be used widely as fuel since other fabrication methods, even for "hot" metal, should be cheaper, and cast uranium has poor radiation stability because of its coarse grains. This probably does not apply to highly enriched uranium where the volume to be handled is small.

It now appears that uranium operating above about 500° C will swell extensively at burnups greater than about 0.2%. This anisotropic growth is probably due to the rare-gas fission products.

Swelling may be a serious obstacle to the use of uranium as a high-temperature fuel, but high-strength cladding may be developed to suppress it

Plutonium. There is not a great deal of experience in the use of solid plutonium as a fuel ("Clementine" at Los Alamos was the only reactor to use it). Because the metal has many allotropic forms and a relatively low melting point, it seems unlikely that it will be used in pure form.

Uranium-rich alloys. The addition of relatively small amounts of elements such as 0.1 wt% Si, 0.5 wt% Al, 0.2 wt% Cr or 0.75 wt% Zr to uranium can give alloys having relatively fine grains. Such alloys make the use of cast or gamma-worked metal more feasible.

Alloys in the 0.1–1% range should find increased applications up to 0.2% burnup and about 400° C

Alloy additions of 2–3 wt%, such as 2% Zr and 3% Mo, produce much better radiation stability than pure uranium. The mechanism of the improvement is not clear but is probably related to fine grains and increased strength. The 2% Zr alloy can be used in the cast condition or after reheating alpha-worked metal to the gamma phase. Serious distortion did not occur with burnups of about 0.3% at about 450° C in EBR–1.

The 2% Zr alloy clad with 20 to 30 mils of Zr shows a negligible distortion after 0.5% burnup at about 400° C. One small-diameter rod clad with only 4 mils of Zr went to 1% burnup at about 500° C without serious change. It is possible that the Zr clad helps the situation in these latter cases. Samples of 2% Zr irradiated at about 800° C showed extensive swelling at 2% burnup.

I believe that 2% Zr alloy will find very extensive use, especially if the fuel is also clad with Zr

Alloy additions of 4–15 wt% have been developed for improved corrosion resistance in high-temperature water. The radiation stability of some of them is also outstanding. Examples of this type of alloy are 12% Mo, 10% Nb, 5% Zr–1.5% Nb, and 4% Si. Under conditions of proper heat treatment (retained gamma phase for the first three alloys), these materials corrode thousands of times more slowly than pure uranium in 600° F water. While none of them are so corrosion resistant that serious attack is completely prevented, the corrosion resistance of these alloys is not greatly impaired by irradiation up to 0.5% burnup.

The 4% Si alloy, if converted to the epsilon phase, corrodes about ten times faster than the 12% Mo alloy, but nevertheless is still very interesting because of the low cross section of Si. The 12% Mo alloy has outstanding radiation stability. Some specimens have been carried to 3% burnup at about 400° C without serious dimensional change. In the Enrico Fermi fast reactor it is planned to use 10% Mo clad with 4 mils of Zr for just this reason.

Some of these alloys, because of their radiation stability, may find use in "fast" reactors, but it is doubtful that any of the alloys in the 4 to 15% range, with the possible exception of the 4% Si alloy, will find extensive use in water cooled reactors for production of commercial power. This statement is based on the fact that such reactors probably would use natural or only slightly enriched uranium and thus could not afford the neutron loss caused by the alloying addition. This judgment obviously does not apply to special purpose reactors where cost becomes a secondary consideration.

Dilute uranium alloys. With highly enriched uranium it is possible to make a fuel that contains only a few percent of uranium. In such alloys the uranium atoms are either atomically dispersed (solid solution) or are concentrated in small regions as in an intermetallic compound.

In the latter case the base material surrounds the compound and is almost uranium-free. Aluminum-uranium alloys are the outstanding example of this latter type. Specimens containing up to 20% uranium by weight can be irradiated at low temperatures of about 200° C until about two thirds of the uranium has been fissioned. Serious trouble due to swelling and distortion does not occur. Apparently, the UAl_4 can maintain its integrity reasonably well and the aluminum matrix holds everything together.

Other alloys of this type, such as UBe_{13} in beryllium or UFe_2 in stainless steel, are worthy of study. With zirconium-uranium alloys the uranium exists principally in a second phase as an ordered structure rather than as a typical brittle compound. Such alloys may be expected to have good radiation stability.

Dilute uranium alloys have been used extensively. The MTR and many research reactors are fueled with Al-U alloy clad with aluminum, and the *Nautilus'* reactor uses Zr-U alloy clad with Zircaloy. These fuels, in the form of plates, rods or tubes, are capable of high performance in terms of heat removal and radiation stability.

Because they contain highly enriched uranium and large amounts of diluent material, which absorbs neutrons, they will be used for special purpose reactors rather than for power. Beryllium-uranium alloys are a possible exception to this.

Beryllium-uranium alloys may be used in commercial power reactors—the fuel can also act as a moderator

Plutonium alloys. Alloys of plutonium, especially dilute ones, should have many possibilities. Plutonium alloys

form many of the same phases as occur in the corresponding uranium alloys. It seems likely that an aluminum-plutonium alloy containing $PuAl_4$ will make as good a fuel element as a similar aluminum-uranium alloy.

Plutonium alloys will eventually come into wide use as a nuclear fuel

Plutonium will be produced in the various natural uranium power reactors and will become increasingly available as time goes on. In addition, the cost of handling plutonium will decrease extensively as knowledge and experience builds up.

Uranium compounds. Chemical compounds have poor thermal conductivity, as compared with free metals, and are brittle. For these reasons reactor builders in the past have considered them to be unlikely fuel materials. In addition, the dilution of the uranium by the other atoms is undesirable for natural-uranium reactors, even if loss of neutrons to the diluent is small. In recent years a great interest in UO_2 has developed because it is not attacked by high-temperature water and because it appears to have good radiation stability. These properties have stimulated interest in the possibility that other compounds may be equally attractive.

The use of massive (as opposed to powdered) UO_2 in PWR is based on the rather revolutionary concept that it is not necessary to worry about the integrity of the core in a fuel element as long as the cladding remains intact. It is found that massive oxide cracks into a number of irregularly shaped pieces (presumably due to thermal stresses) in the early stages of use. The situation apparently stabilizes itself with the pieces exhibiting good radiation stability (no swelling) even at very high temperatures and, apparently, with good probability that the cladding surrounding the oxide will not break open or distort in spite of the cracking within.

It is obvious that the maximum temperature inside a cracked core will be difficult to predict. Furthermore, the thermal conductivity of the oxide decreases by at least a factor of two during irradiation. These uncertainties mean that heat-removal rates must be held down in order to ensure that the oxide does not melt somewhere in the interior.

Massive oxides have been irradiated until 3% of the uranium atoms have fissioned without obvious disintegration occurring. This not only shows that the chemical bonds between uranium and oxygen persist but also demonstrates that the crystals of UO_2 have an unusual ability to accommodate "foreign" atoms, even rare gases. There is a great deal of conflicting data on the release of rare gases as the result of the fission of UO_2, but it is clear that a good portion of the gas is held in the crystal. This has led to the suggestion that chemical compounds may be better able to accommodate fission products than free metals.

It seems likely that massive UO_2 or some similar compound (ThO_2 containing UO_2) will be used in a number of pressurized water reactors in the next few years. As time goes on, however, there will be an increasing demand for higher performance in order to get more economical power. It seems inevitable, therefore, that pure uranium fuels will be made reliable even for water reactors and that the use of the massive oxides will decline.

It is conceivable that intermetallic compounds may be as capable of retaining fission products as is UO_2. Such compounds may have better thermal conductivity than the oxide and, hence, be better suited for high-performance water reactors. This may be a fruitful field for study.

There will be a demand for reactors capable of producing heat at temperatures above the melting point of uranium and its solid solution alloys. For such applications, gas-cooled reactors may be the answer, and oxides, carbides, and intermetallic compounds, perhaps dispersed in other materials such as graphite or silicon carbide, will come into use. It is clear that compounds of uranium and plutonium are deserving of study for very high temperature use in gas-cooled reactors.

Massive oxides will see use in pressurized-water reactors in the next few years. They will find their greatest use thereafter in gas cooled reactors

Compounds can be dispersed in a metallic matrix by various forms of powder metallurgy. Examples of this are UO_2 in aluminum or stainless steel.* It is generally considered that the particles of the compound should be substantially larger than the range of the fission fragments in order to minimize damage to the metallic matrix. In view of the apparent radiation stability of compounds, this point seems significant, if not yet proven.

A large fraction (perhaps 75%) of the uranium atoms in a dispersion-type fuel can be fissioned without serious damage to the fuel element. These fuels can be employed in either water, liquid-metal, or gas-cooled reactors. Obviously, the matrix metal and the amount of uranium used must be chosen to meet the circumstances.

The use of dispersion type fuels probably will be limited to special purpose reactors. Loss of neutrons to the matrix mitigates against their use for producing economical power.

Fluid fuels. The potential of fluid fuels for avoiding radiation damage and achieving high power densities with continuous removal of fission products is well known. In principle these fuels should be ideal for achieving low-cost power, but this will not be achieved until certain practical difficulties are overcome.

The fluid fuels that seem to have practical application fall into the same three categories as did the solid fuels. These are: (a) free metals such as liquid plutonium; (b) alloys such as liquid U-Bi; and (c) compounds such as aqueous solutions, fused salts, and slurries. The first two categories can be lumped together under the heading of liquid metals. Each type fuel in the third category, however, will be treated individually.

Liquid metals. Not much can be said about liquid free metals because there has been no experience to date and only liquid plutonium is even being contemplated (for LAMPRE). The problem here, however, is that the information is classified.

The solubility of uranium in low-melting-point metals

* A two-phase alloy with the uranium present as an intermetallic compound may also be regarded as a dispersion-type fuel.

in the range up to 500° C is very low. The greatest solubility at a given temperature is in bismuth, and this is particularly interesting since bismuth has a low absorption cross section. It appears that graphite is a satisfactory container for this alloy inside the reactor and that low chromium steels may be useful for the external circulating system. Addition of small amounts of zirconium to the liquid alloy reduces the attack on these container materials. Some problems still remain to be solved with regard to pipes, pumps, and valves for a system with high flow rates.

It is believed that the fission products will not affect the problem of keeping the uranium in solution in the bismuth, but this subject requires further study. Procedures for continuous removal of fission products also need development. All of these problems do not seem insurmountable and, therefore, the liquid U-Bi fuel looks very promising.

Liquid aluminum will dissolve 20–30 wt% of uranium or thorium or both together at temperatures of 700–800° C. Container problems for this alloy would be difficult, but not insurmountable. For example, a scheme has been proposed to use molten lead as both a container and a coolant.

Uranium forms eutectic alloys with the transition metals iron, nickel, manganese, and chromium, which melt in the range 725–850° C. These alloys might be used as fluid fuels that would not necessarily be circulated. It has been found that certain higher melting metals can contain these eutectics for hundreds of hours.

I believe that liquid metal fuels, both uranium and plutonium, offer great promise for reactors of the future. However, their use, with the exception of the bismuth alloy, may not come about for twenty or thirty years.

Aqueous solutions. A number of aqueous solutions of enriched uranium or plutonium salts can be used to achieve a chain reaction with a low critical mass. At one time it was feared that gas production from decomposition of water would make it difficult to control the reactor, but this problem has been overcome. However, to produce economical power from aqueous fuels, it is necessary to operate at relatively high temperatures (above 200° C) and pressures. This leads to other difficulties. At elevated temperatures the uranium salts tend to hydrolyze, and it becomes necessary to add the appropriate acid to prevent this. The resultant solution is highly corrosive and this leads to container, pump, and valve problems. The metals zirconium, titanium, and type 347 stainless steel are considered to be the most promising materials for use with uranyl sulphate solution. Unfortunately, even these, in the presence of reactor radiation and under high flow rates, exhibit excessive corrosion rates.

It is conceivable that the corrosion problems for aqueous fuels will be successfully solved. When this is accomplished, the aqueous homogeneous reactor should become more attractive than pressurized water reactors, especially if the former can be made a breeder.

Slurries. Many people have recognized that a dispersion of fine particles containing uranium, plutonium, or thorium in a suitable liquid offers many of the advantages of a fluid fuel without some of the attendant problems of corrosion. New problems are introduced, however, concerned with preservation of flow properties, avoidance of settling, and the attack on containers and pumps by a combination of erosion and corrosion.

Flow properties are a function of particle size for a given concentration of solids. It is found that particle-size changes during circulation but presumably reaches some sort of steady state. Very little is known about the effects of radiation on the particle size. Damage to the particles, other than change of size, is presumably of no concern.

It seems likely that flow systems can be devised that will successfully cope with the settling problem, even in cases where the densities of solid and liquid differ widely. Erosion by the circulating solids can be avoided by using materials of suitable hardness at critical points. Corrosion by the dispersing fluid may be more difficult to control, since the solid particles can continuously remove the thin surface films that generally protect against corrosion.

Slurries of UO_3, UO_2, and ThO_2 in high-temperature water are being extensively studied. Some attention has also been paid to intermetallic compounds and powdered uranium in low-melting metals such as bismuth and sodium. It is difficult to guess which of these various systems have real promise because much work remains to be done. The first use of slurries may be as blanket materials in thermal breeders rather than as fuel.

Fused salts. Fuels made of mixed fluorides of uranium, zirconium, and beryllium have been extensively studied in the molten state, and an experimental reactor (ARE) using this material has been operated. Alloys to contain the fuel have been developed to the point that long-time operation is assured. Unfortunately, these alloys exhibit relatively large neutron absorption.

Fused-salt reactors are of interest chiefly for special purposes

Conclusions. Solid fuels will be widely used for at least the next ten years. Most of these will consist of uranium-rich alloys, but massive oxide will also be used in the immediate future. The presently known difficulties with uranium, especially at elevated temperatures, will be overcome and, as a consequence, the oxide will be used only for very high temperature service of specialized types. Dilute alloys of uranium and the various types of dispersion fuel elements will be used for applications not aimed primarily at cheap electric power. Fluid fuels and slurries will become of increasing importance as the necessity for breeding becomes established.

In thirty to fifty years, fluid fuels will be the principal source of economical power

There is still only a small body of knowledge of nuclear fuels that is the result of extensive operating experience. Most of the existing data, with the exception of that on unalloyed uranium and a limited number of uranium containing alloys, are based on laboratory experiments or small-scale, in-pile tests. Under the circumstances, many of the statements made in this article must be regarded as opinion, perhaps prejudiced, that may well be altered by further developments in knowledge of materials, technology of nuclear reactors, availability of uranium and thorium, and cost of power from other sources.

At NUCLEONICS' Request

A Nobel Laureate Looks into the Future

Berkeley, California

I SHALL CONFINE my predictions to an area in which I have had a great deal of interest in recent years, namely new synthetic elements. The search for new synthetic elements heavier than nobelium (number 102) is a continuing effort.

The prediction of the chemical properties of these elements seems to be quite straightforward. Element 103, corresponding to Lu in the rare-earth series, should complete the actinide group.* This will involve filling the 5f shell of electrons, which, like the similar shell (4f) of the rare-earth group, has 14 places. Element 103 will be chemically identified by the ion-exchange adsorption and elution technique.

It is expected that element 104 will begin a new series, whose members will correspond to Hf, Ta, W, and so on. This series would end with the filling of the 6d shell. The next series, assuming that heavier elements could be found (which is very doubtful) would fill the 7p shell and would close with hypothetical element 118. The chemical properties of all of these elements can be estimated from their postulated positions in the periodic table.

The prediction of decay properties is not so straightforward, but nevertheless some predictions of apparent value can be made. As we go up in atomic number, beginning with fermium, decay by spontaneous fission for even-even nuclides apparently will become nearly as common as decay by the emission of alpha particles. Unfortunately, the half-lives become shorter and shorter with increasing atomic number. The predictable regularities for both alpha and spontaneous-fission decay are most easily discernible in nuclei with an even number of protons and an even number of neutrons. Fortunately, isotopes with an odd number of protons or neutrons or both have slower decay rates than do those of the regular even type.

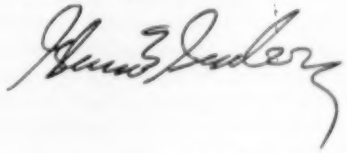
Producing such new synthetic elements presents equally difficult problems. One method to consider is multiple neutron capture as the result of intense neutron bombardment over long periods of time. Unfortunately, this method seems to hold little promise because some of the intermediate isotopes that must capture neutrons have half-lives so short as to preclude their presence in sufficient concentrations. Thus, this method should not become important until higher neutron fluxes, say of the order of 10^{16} n/cm²/sec become available.

Bombardment with deuterons or helium ions, which has previously been used successfully, also does not seem to offer encouragement. The half-lives of the transfermium isotopes are so short that it would be difficult to build up a sufficient quantity of target material.

Fortunately, there is a type of nuclear reaction that seems promising. This is bombardment with heavy ions—that is, ions heavier than those of helium. A number of interesting reactions of this type have already been observed and nobelium was first produced in this manner. However, the proportion that goes into any particular spallation reaction appears to be of the order of one part per million of the total reaction cross section or less, and this seems to decrease drastically with increasing atomic number of the product nucleus.

By the time elements 104 and 105 are reached, we shall probably find that the longest-lived isotopes that can be made will exist barely long enough to enable chemical identification. We can be quite sure that we shall be relying entirely on isotopes containing an odd number of nucleons to make chemical identifications, if these are possible at all, for atomic numbers so high.

It is likely that the present criteria for the discovery of a new element, namely, chemical identification and separation from all previously known elements, will have to be changed at about this point. Actually, careful measurements of decay properties, including in optimum cases the measurement of characteristic X-rays taken in conjunction with careful predictions using the systematics of decay, should eventually allow the extension of identification to several atomic numbers above 105.



Glenn T. Seaborg, *of Radiation Laboratory and Department of Chemistry of the University of California, corecipient with E. M. McMillan of 1951 award in chemistry for discoveries in chemistry of transuranium elements.*

* G. T. Seaborg. Place in periodic system and electronic structure of the heaviest elements, NUCLEONICS **5**, No. 5, 16 (1949).

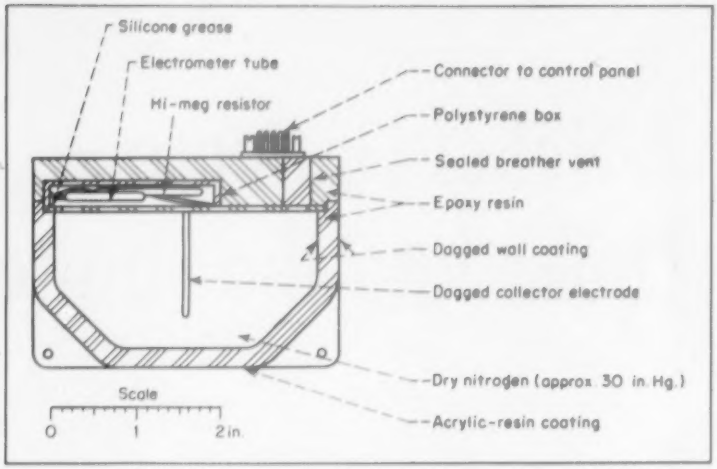


FIG. 1. Encapsulated ion-chamber unit is independent of temperature and pressure and has 25-yr life. Silicone grease isolates components from possible leakage paths

Encapsulation Makes Monitor Independent of Environment

By MARTIN H. JACHTER and ABRAHAM E. COHEN
U. S. Army Signal Engineering Laboratories, Fort Monmouth, New Jersey

In response to requirements for environmental independence in the field of gamma-ray measurements, we have developed design and fabrication techniques for ionization-chamber instruments. An encapsulated ion chamber and electrometer, the critical components of the instrument, are described here.

Instruments incorporating the new technique have been evaluated for about 2 years. This technique permits the encapsulated unit to meet the specifications listed in the table.

The best approach was to "pot" with epoxy resin* those components likely to be affected by extreme environments and in addition providing a hermetically sealed ionization chamber.

There are several advantages in using epoxy resin: It requires little specialized apparatus. It can be cast at temperatures permitting encapsulation of plastic components with low melting points. It does not become deformed when heated to several times the normal temperature of formation. It has high volume resistivity and low average atomic number.

The temperature coefficient of resistance for epoxides† prevents their use in contact with high-impedance components. Epoxides have a vol-

Instrument Specifications

Instrument radiation specifications	
Type detector	Unsaturated ionization chamber
Radiation	X- and gamma rays
Energy response	70 kev to 3 Mev ± 3%
Sensitivity	100 mr/hr to 2,000 r/hr
Accuracy	±10%
Calibration stability	±5% over 360 hr
Environmental specifications	
Temperature	−60° to +160° F
Humidity	0–100%
Pressure (atmospheric)	To 0.1 mm Hg
Shock	1,200 ft-lb
Vibration	0–55 cps, acceleration 1 cps
Acceleration	100 g
Salt spray	100 hr

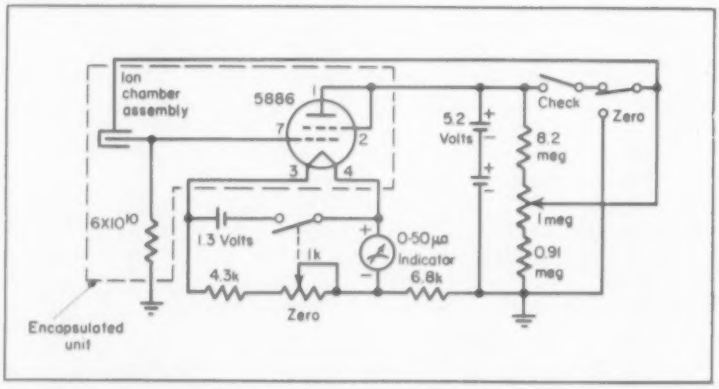


FIG. 2. Circuit of detection instrument. Encapsulated components are within dashed lines

* *Potting with Epoxy Resins*, William H. Crandell, Electronic Design 4, No. 23 (1956).

† *Thermal Properties of Encapsulating Materials*, Erich T. Linden, SCEL, Fort Monmouth (Symposium on Casting Resins, sponsored by the Armed Services at Diamond Ordnance Fuse Labs., National Bu. Standards, Washington, D. C., Jan., 56).

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ume resistivity of 1×10^{14} ohm-cm at room temperature and normally provide a suitable encapsulation medium. However, at temperatures above 90° F, the volume resistivity of the epoxide diminished to 10^{12} ohm-cm and produced an input impedance shunt to the electrometer.

It was necessary to prevent the encapsulating material from serving as an insulator or from coming into contact with the high-impedance components at any point. This was done by providing a compartment filled with pure silicone grease for the electrometer tube and high-meg resistors, isolating the components from any leakage path.

The coefficient of expansion of epoxy resin is such that at temperatures below −40° F, the resin tends to crack, due to shrinkage, causing the fragile electrometer-tube envelopes to crack. This cracking is overcome by the mechanical-shock absorbence of the silicone-grease compartment. In an encapsulated unit, the failure of one component requires replacement of the entire unit. Therefore it is necessary to keep the number of components within the encapsulation to a minimum. Only components requiring protection of the encapsulating material were included.

Special techniques are required in the preparation of epoxy resin to produce its optimal properties. The following procedure was used: Combine 300 gm "Epon 828" with 31.5 gm "Curing Agent D," to which is added 100 gm of 325-mesh silica flour to reduce the temperature coefficient of expansion. Heat the mixture to 100° C to acquire minimum viscosity and then pour to a depth of $\frac{3}{8}$ in. in a 4,000-ml beaker. Place the beaker in a vacuum chamber and pump down to 0.1 psi to remove trapped air from the mixture. Observe the material during gas removal to prevent boiling at the reduced pressure. The gas-free point is reached when the solution becomes clear of bubbles. Repeat the evacuation process until the entire volume of resin has been processed. Then pour the mixture into a greased mold and cure in an oven for 4 hr at 60° C. Remove the breather vent that relieves the air pressure in the chamber during oven curing, and flush and fill the chamber with dried nitrogen at sea-level pressure. Plug the chamber-mold pin holes and ion-chamber breather, and fill with epoxy resin. The final hermetic seals are made possible by the cohesion of epoxy materials.

The ion chamber is shown in Fig. 1;

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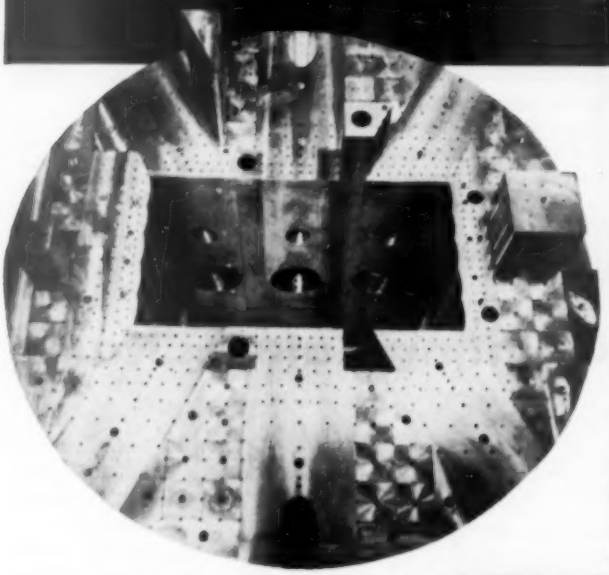

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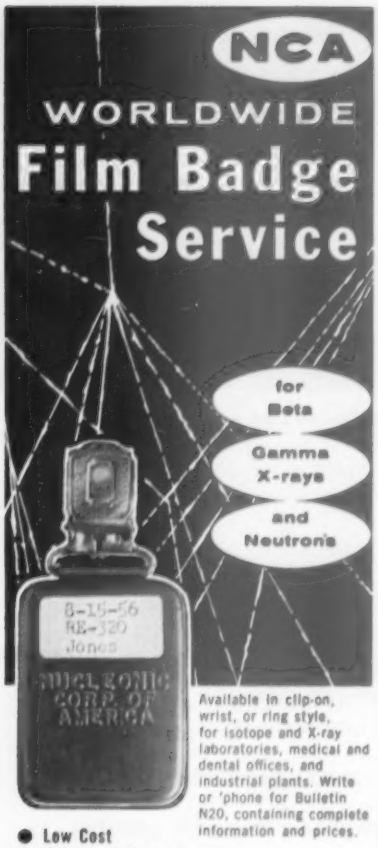

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the chamber wall is 1 cm thick to permit maximum resistance to the air-pressure gradient at extreme altitudes and to provide air equivalency over the range 0.080–1.25 Mev. The entire assembly was coated with aquadag fixed with an acrylic spray to minimize stray capacitance effects. Figure 2 shows a typical detector circuit.

Life expectancy of the unit was determined by the shortest-lived component encapsulated—i.e., the electrometer tube. A JAN-5886 electrometer tube operating at rated conditions were used. To date laboratory tests indicate a life in excess of 50,000 hr for JAN-5886 electrometer tubes at rated conditions. It appears that the tubes may be guaranteed to operate continuously for 25,000 hr. Based on a 1,000-hr operating time per year, a potential useful 25-yr life can be expected for the ion-chamber module.

Heat dissipated by the electrometer tubes encapsulated in the silicone grease was not detectable with thermocouples placed adjacent to them while operating test units. The circuit was designed so that it would not be necessary to use a shorting switch for "zeroing-in a radiation field" in the high-impedance input region; this eliminated the possibility of extracameral or secondary chamber response.

It is felt that incorporating this encapsulation technique in ion-chamber instruments will make possible a high-quality radiological detection instrument for use by unskilled personnel in extreme environments.

* * *

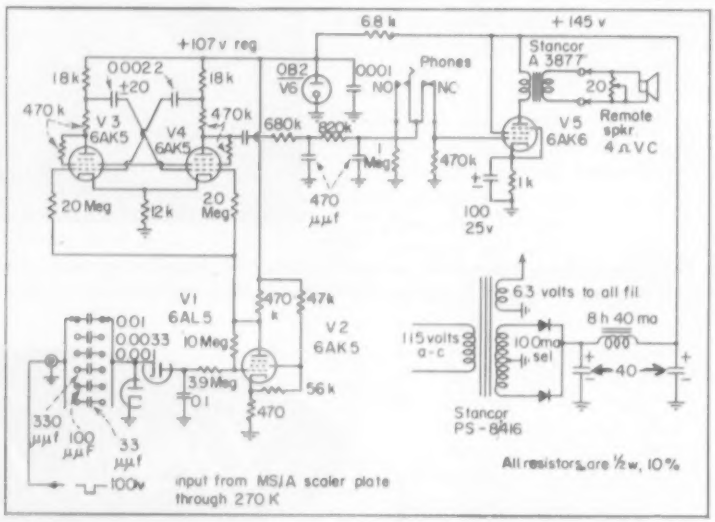
The work described in this paper was greatly aided by the wholehearted cooperation of Messrs. Joseph Crotchfeld, Kristian Nilson, Henry Brown, Harry Murphy, and Robert Chapin of the U. S. Army Signal Engineering Laboratories.

Aural Counting-Rate Indicator

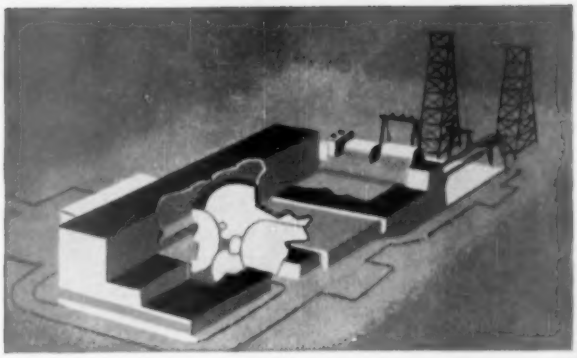
By C. C. HARRIS, P. R. BELL and J. E. FRANCIS

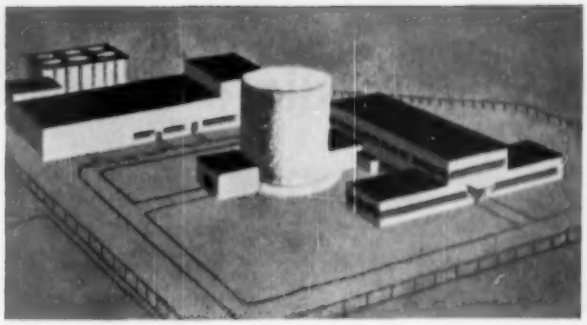
Oak Ridge National Laboratory
Oak Ridge, Tennessee

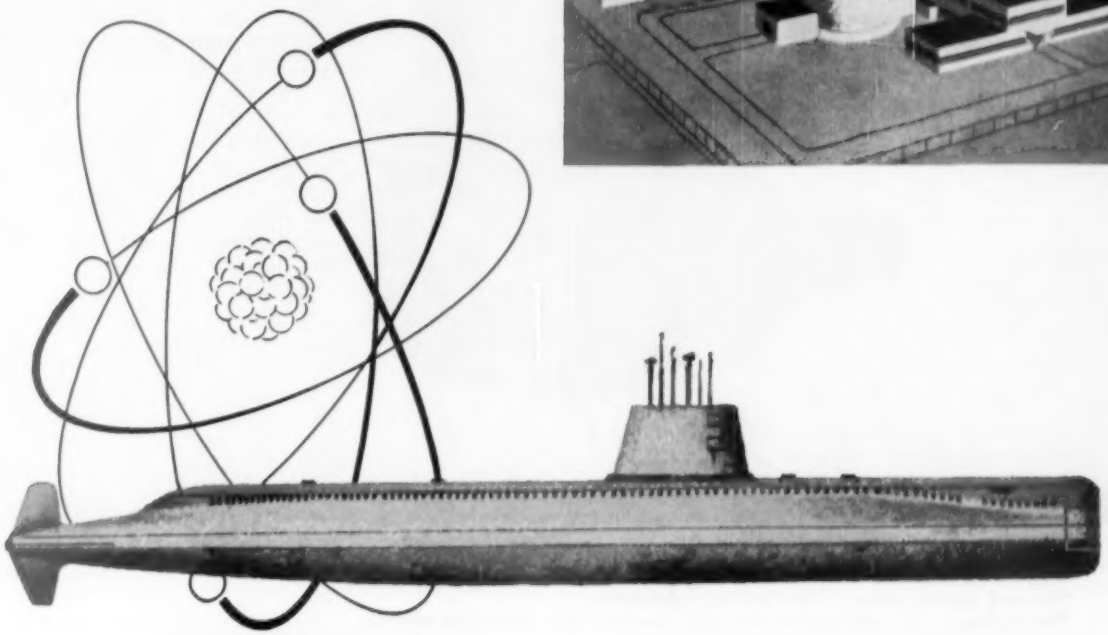
The use of single-channel pulse-height analyzers and spectrometry for routine gamma-ray counting is becoming quite widespread. The fields of nuclear medicine, radiobiology, radiochemistry and reactor-waste monitor-



AURAL COUNTING-RATE INDICATOR for spectrometer alignment. Circuit operation: Diode pump circuit V_1 operates from plate signal of scale-of-two or univibrator driven by single-channel analyzer and varies grid potential of V_2. Grid return of free-running multivibrator V_3 and V_4 is connected to plate of V_2. As plate potential of V_2 varies from few volts to nearly that of B+, multivibrator frequency varies from about 30 to 3,000 cycles. Multivibrator frequency can be varied about 100:1 on as little as 25 cps out of analyzer. Multivibrator signal is filtered and passed to headphones or speaker. Simple power supply permits compact construction







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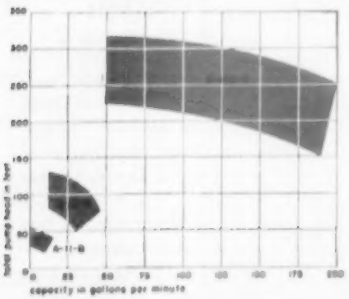

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net positive suction head required, feet	4	5	12
Electrical Characteristics			
line	220/60/3	220/60/3	440/60/3
rated kw input	.6	5.75	17.0
amperes per line	2.7	20.0	25.0
Dimensions and Weights (not to be used for construction)			
overall height	11⅜"	27⅛"	32⅛"
max. diameter	8⅞"	11"	16⅛"
suction nozzle, pipe size	¾"	1½"	3"
discharge nozzle, pipe size	½"	1¼"	2½"
weight, pounds, (approx.)	60	265	1025

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ing, as well as physics, are employing this important tool.

One of the problems in using spectrometry is aligning the position of the "window" of the analyzer to encompass the pulse heights representing gamma rays of a particular energy region, most often a full-energy peak.

Conventional counting-rate meters are often used for alignment purposes. When aligning the equipment, however, it often is desirable that the operator be able to watch the variable being adjusted.

Many persons have also used the sounds from electromechanical registers following scalers connected to the output of single-channel analyzers for aural monitoring of counting rate, but this is not wholly satisfactory.

An aural counting-rate indicator of the type to be described removes much of the effort and error in setting the analyzer on a particular peak. This device, often called a "howler," gives an audio note that varies approximately logarithmically with input counting rate. Because of its large frequency variation, even a very short time constant provides satisfactory smoothing of the fluctuations in counting rate.

This device is similar to, but simpler than, the indicator used on the surgical probe reported previously.* Although designed to operate from the 100-volt scaler plate swing in the MS1A medical spectrometer,† the "howler" can be driven from any scaler or univibrator with a sensitivity proportional to plate swing.

To adjust the position of an analyzer "window," one adjusts the energy control to the setting that produces the maximum tone frequency. On the most sensitive range, single counts can be heard, but because of the smoothing due to integration, changes in rate can be reliably detected at much lower rates than possible with "pops" as used in most survey meters.

With this device, counting-rate changes of a very few percent can be quickly and reliably detected, and it is very accurate for spectrometer alignment. If the spectrum of a given emitter is known, this device is useful for checking the relative position of the various counting-rate peaks.

---

* C. C. Harris, R. R. Bigelow, J. E. Francis, G. G. Kelley, P. R. Bell. A CsI(Tl)-crystal surgical scintillation probe, NUCLEONICS **14**, No. 11, 102 (1956).

† J. E. Francis, P. R. Bell, C. C. Harris. Medical scintillation spectrometry, NUCLEONICS **13**, No. 11, 82 (1955).

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Molecular Sieves Adsorb Iodine-131 from Air

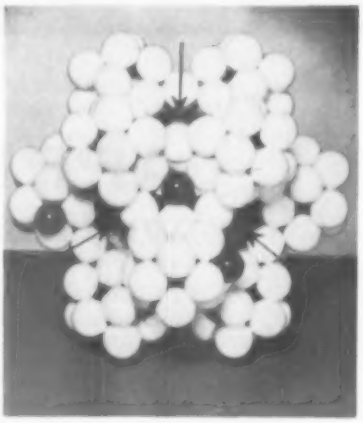
By MORRIS A. WAHLGREN and W. WAYNE MEINKE
Department of Chemistry, University of Michigan, Ann Arbor, Michigan

The disposition of low levels of gaseous I^{131} evolved during radiochemical laboratory, hospital, and reactor operations is accomplished routinely by dilution with air and discharge from a suitable elevated stack. The higher activity levels encountered in isotope production, reactor-fuel processing, and anticipated in the event of reactor malfunction, require additional provisions for environmental protection. This has been achieved in the past with scrubbing columns, absorption tubes, etc.

Work in this laboratory indicates that a satisfactory decontamination (10^3–10^5) can be obtained by adsorption of I^{131} on a molecular sieve (*1*) column.* The molecular sieve is a synthetic zeolite with a definite crystalline structure containing a large number of small caves interconnected by a number of still smaller holes or pores. These cavities and pores are precisely uniform in size. Normally these cavities contain water, but when the sieve is heated the water is driven off, leaving the physical structure unchanged. The empty cavities then comprise almost 50% of the total volume of the crystals. There is a strong tendency for these cavities to fill up again with water, and hence the sieves act as a good desiccating agent. If no water is available, then any material can be adsorbed in the cavity if it can pass through the pores. Molecular sieves are available with pore sizes of 3-Å, 4-Å and 5-Å diameter (*2*).

The I^{131} tracer† used in these experiments was oxidized in aqueous solutions (*2*), along with a small amount of added carrier. It was then distilled into an air stream drawn first through a small column containing the molecular sieve and finally through a sodium thiosulfate scrubbing system. The loss of tracer by adsorption on the walls of the equipment was greatly reduced by application of "Dri-Film."‡

In preliminary experiments with a molecular-sieve column, two types of behavior were observed. With the 3A form (pore size ~3 Å) a small amount of iodine adsorbed on the column and could be displaced almost quantitatively by water in the manner of adsorption chromatography. When the 5A form was used, both iodine and water were readily adsorbed at the same time. With this size sieve the iodine apparently entered the cavity since washing the column with various aqueous solutions and with methanol



ZEOLITE CRYSTAL UNIT of molecular sieve contains transverse pores (indicated by arrows). Pore size determines adsorption selectivity of sieve; molecule must be smaller than pore size (3, 4, or 5 Å) to be adsorbed—thus I^{131} is adsorbed by 5 Å sieve but not by 3 Å. White spheres are oxygen and dark are sodium or calcium. Sieves operate in gas or liquid phase. They adsorb polar (e.g., water) in preference to nonpolar molecules, unsaturated in preference to saturated molecules. Thus they are used for drying gases and separating organic molecules

* Molecular sieve obtained from Linde Air Products Co., Tonawanda, N. Y.

† Iodine-131 tracer obtained from the Isotopes Div., U. S. Atomic Energy Commission, Oak Ridge National Laboratory, Oak Ridge, Tenn.

‡ Dri-Film 9987, produced by General Electric Co., Organosilicon Products Div.; obtained from Cenco, Chicago, Ill.

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removed less than 1% of the iodine.

On a laboratory scale, a measured decontamination of at least 10^3 was obtained with air pulled at about 50 cm^3/min through a small column (Fig. 1) containing about 30 gm of type-5A adsorbent. Decontamination was also measured with a scaled-up column (Fig. 2) at an air flow of about 1 ft^3/min. The activity distribution along the length of this column was determined by measuring representative sections of the column and is shown to be around 10^5 in Fig. 3. The anomalous behavior of the first two

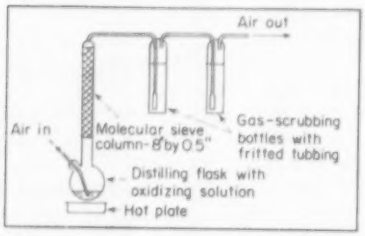

FIG. 1. Setup used for preliminary small-scale I^{131} decontamination of air

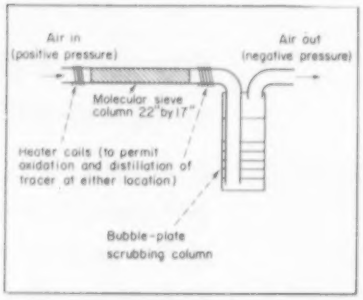
Air in (positive pressure)
Air out (negative pressure)
Molecular sieve column 22" by 17"
Heater coils (to permit oxidation and distillation of tracer at either location)
Bubble-plate scrubbing column

FIG. 2. Scaled-up (1 ft^3/min) column and scrubber system for I^{131} decontamination

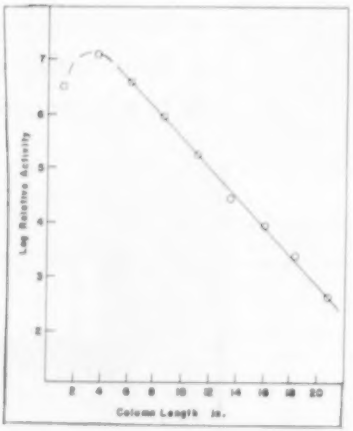

FIG. 3. Distribution of I^{131} adsorbed on 5A-molecular-sieve column from air passed through at 1 ft^3/min

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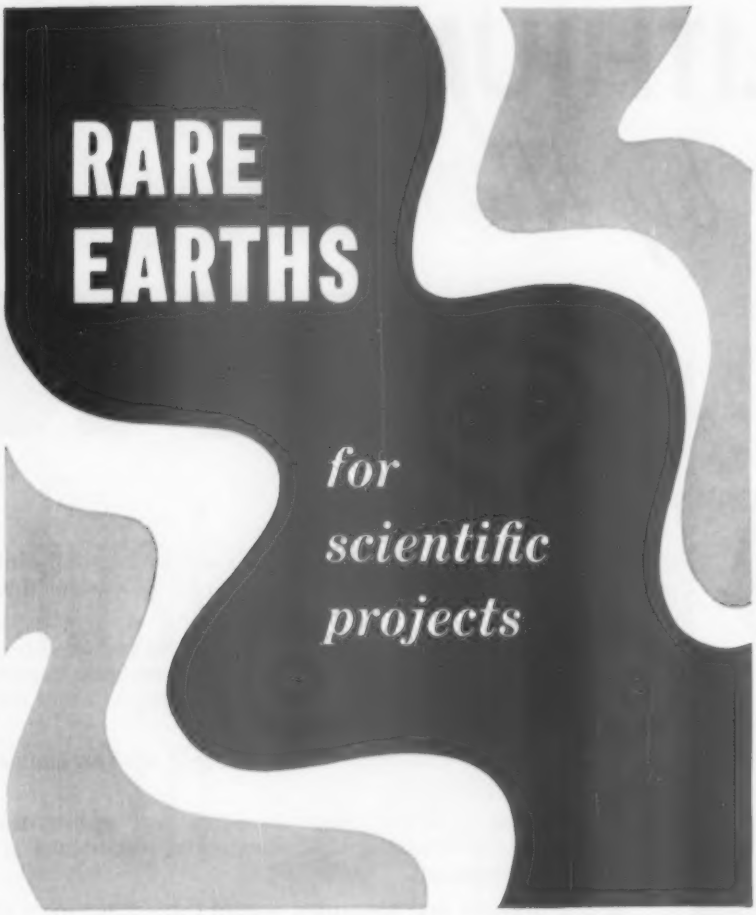

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points are due to the saturation of the first part of the column with water vapor present in air that was drawn over the column before the tracer run. The gas-scrubbing system at the end of the column gave a material balance of the iodine used, indicating that all the iodine could be accounted for in the column.

The preliminary air drying that would be necessary in any long-term operation of such a column could be obtained by passing the air through a column filled with the 3A form of molecular sieve before passing through the 5A column. The 3A column could be maintained, if necessary, at a slightly elevated temperature to allow selective adsorption of the water. The drying columns would be alternately dehydrated, as necessary, by heating and purging.

Essentially irreversible adsorption of iodine was found to take place in the tracer runs when the distillation was made from nitric-acid–sodium-nitrite-solution. A large part of the activity was retained on the column even after purging at 500° C for 24 hr. Similar results were obtained when the iodine was distilled from H_2SO_4 solution into a column that had been preexposed to vapors of an HNO_3-$NaNO_2$ solution. This anomaly seems to imply a reduction of the iodine to iodide by oxides of nitrogen adsorbed on the columns.

It may be possible to utilize this irreversibility of the iodine adsorption in the presence of low concentrations of water and oxides of nitrogen. A small column maintained under these conditions at 375° F, a temperature at which water will not adsorb on the 5A sieve, gave an iodine decontamination of greater than 100 over a several-hour period. The useful life of the column under these more rigorous conditions is not known.

An iodine decontamination system utilizing the molecular sieve, if proven feasible in engineering tests, could offer economy, compactness and high efficiency. A column saturated with iodine could be reused after storage for several months to allow essentially quantitative decay of the iodine to inactive and desorbing xenon.

* * *

This work was supported in part by the U. S. Atomic Energy Commission.

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2. M. Kahn, A. J. Freedman, C. G. Shultz, NUCLEONICS **13**, No. 7, 72 (1954)

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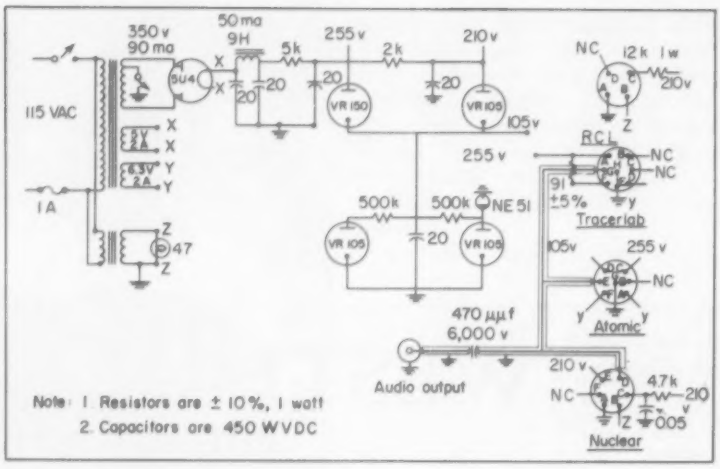

FIG. 1. "Scintiverter" power supply circuit

Power Supply for Interchanging Scintillation Counters and Scalers

By W. L. SCAFF, K. E. BAGWELL and P. C. JOHNSON
Radioisotope Service, Veterans Administration Hospital
Oklahoma City, Oklahoma

Most large radioisotope laboratories have several scalers, purchased from various manufacturers, which can only be connected to certain scintillation wells or medical scintillation detectors. Even though all makes of scintillation detectors are essentially alike electronically, the differences in the required B power supply and the use of different connectors for attaching them to their respective scalers make it impossible to interchange conveniently one manufacturer's scaler with another's scintillation detector. Because of this, the attached scintillation detector is no longer usable whenever scaler breakdown occurs.

To circumvent this difficulty, we have constructed a power supply, which we call a "Scintiverter," that allows us to interchange scalers and detectors by supplying to the detector the required B and C voltages. By making use of the replacement scaler's

Connectors Used on Nuclear Equipment

Manufacturer	*Outlet*	*Chassis socket*	*Cable plug*
Tracerlab	High voltage	82-515	82-532
	Preamp	AN 3102A-18-8S	AN 3108B-18-8P
Nuclear-Chicago	High voltage	83-1R	83-1SP
	Preamp	AN 3102A-14S-6S	AN 3108B-14S-6P
Atomic Instr. Co.	High voltage	31-003	31-012
	Preamp	AN 3102A-16S-1S	AN 3108B-16S-1P
Radiation Counter Laboratories	High voltage	82-805	82-804
	Preamp	AN 3102A-14S-2S	AN 3108B-14S-2P

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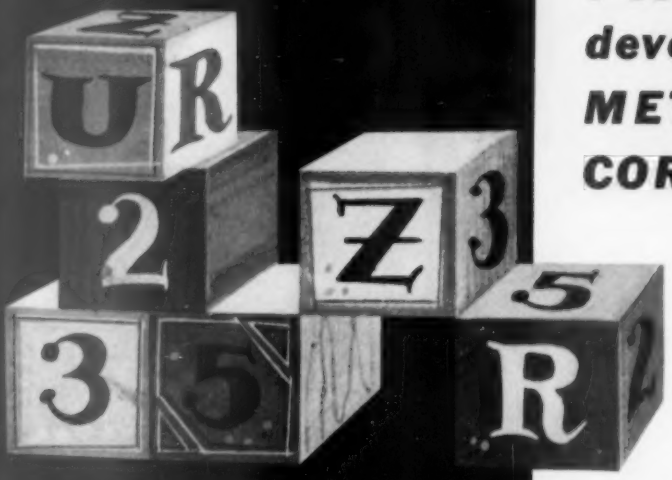

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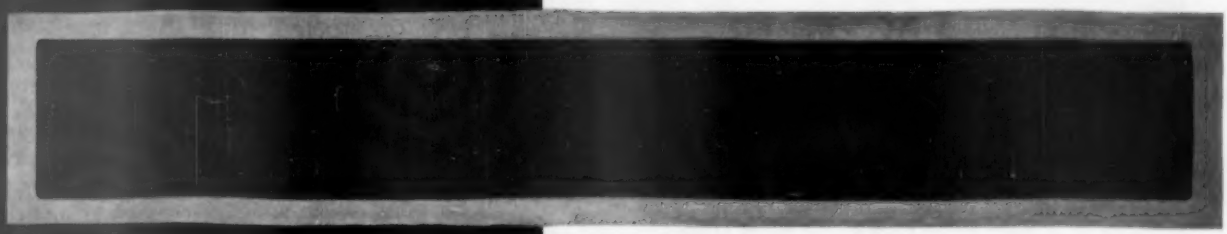

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A typical specification is: weight of fuel, 3 to 25 grams; element length, 6″ to 30″; element width, ¼″ to 2½″; element thickness, .013″ to .025″ ± .002″; fuel thickness, .0005″ to .0025″ ± .0001″ to .0003″; cladding thickness, .005″ to .010″. Other variations of dimensions on application.

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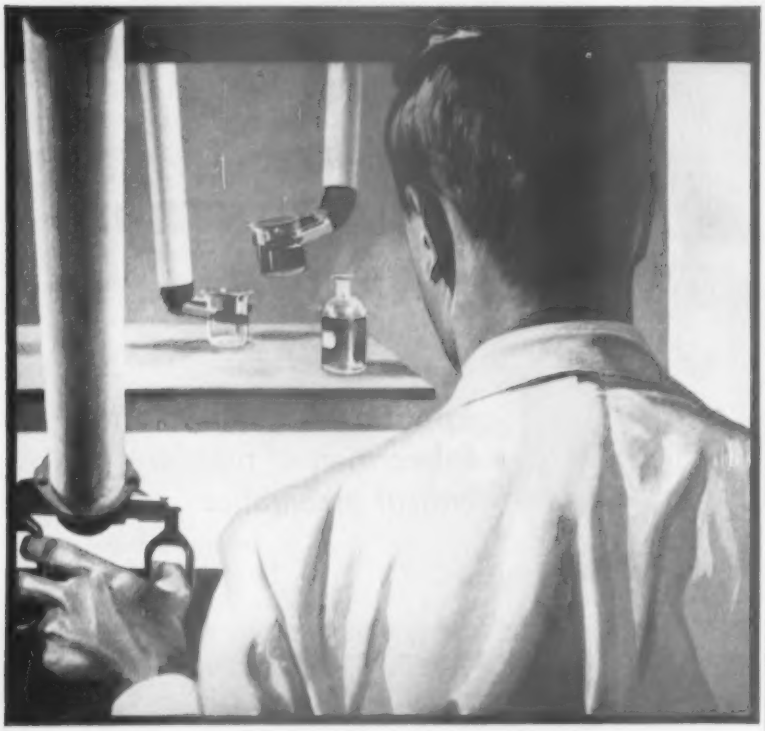

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regulated high-voltage supply for the photomultiplier, we were able to simplify this power supply. This was inexpensively accomplished by constructing high-voltage adapter plugs that allow us to interconnect any scaler's high-voltage output to any detector.

The power supply is shown in Figs. 1 and 2. It was constructed for approximately $45.00, and it is housed in an 8 × 8 × 10-in. sloping-panel utility cabinet. The preamp connections for

FIG. 2. Power supply for interchanging scalers and scintillation detectors. It cost $45 and is housed in 8 × 8 × 10 in. cabinet. Preamp connections for detectors are in rear of chassis. Audio output on front panel is connected by shielded cable to input plug of replacement scaler

the scintillation detectors are in the rear of the chassis. The audio output on the front panel is connected by a shielded cable to the input plug of the replacement scaler.

Radiation Counter Laboratories' scintillation detector has the audio output in the high-voltage line. With this detector, the high-voltage connector is placed into the combined input and high-voltage connector (usually called G.M.) of the replacement scaler and the audio output of the Scintiverter is not used.

The variable high voltage of the scaler is attached to the photomultiplier by constructing high-voltage adapters that consist of appropriate plugs and sockets connected back to back. With this arrangement, only one high-voltage cable is required. The necessary connectors needed for four brands of scalers and scintillation detectors are listed in the table.

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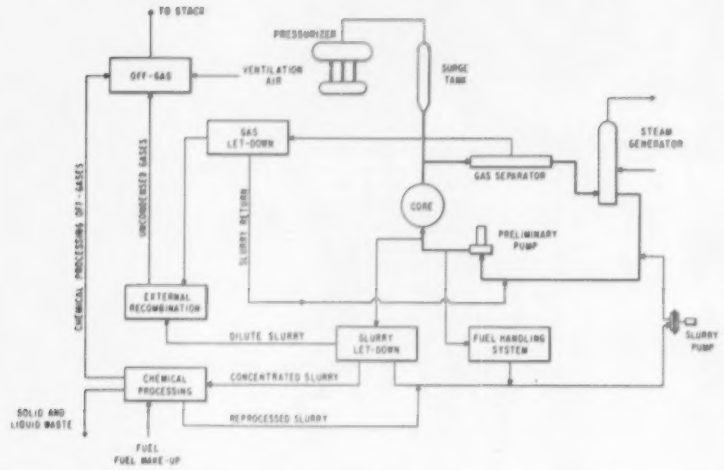


FIG. 1. Flow chart of Pennsylvania Advanced Reactor shows one of four primary steam generating loops in present reference design. Chemical reprocessing will be carried out as continuous process during reactor operation

PAR Homogeneous Unit Gains; Corrosion Seems Licked

By JOHN E. KENTON
News Editor, NUCLEONICS

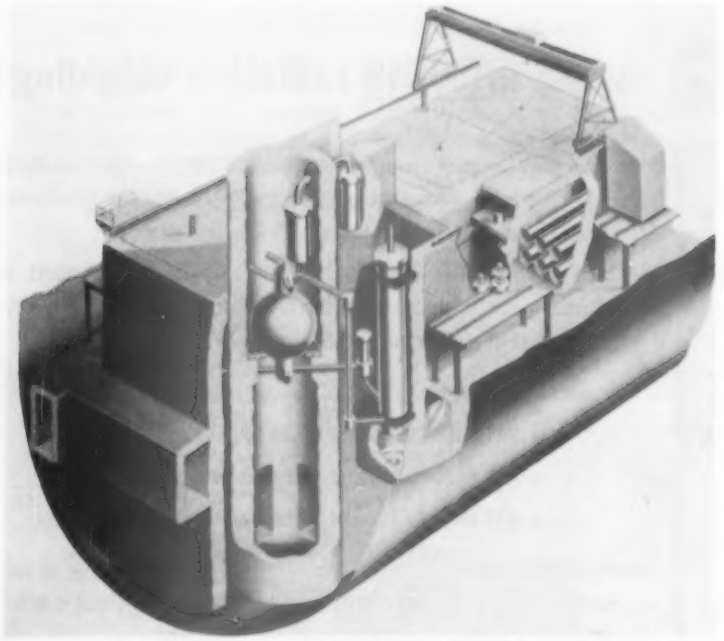


FIG. 2. Isometric sketch of new reference design shows heavy shielding around reactor core, and to left, personnel galleries for limited access to plant during operation. Compare with elevation, plan drawings on facing page

Two years ago, in July 1955, Westinghouse and the Pennsylvania Power & Light Co. of Allentown, Pa., announced that they would jointly develop, for PP&L's grid, the world's first commercial-size (150-Mw) aqueous homogeneous power reactor.

For the project was then announced as being optional—conditional on the development work proceeding far enough by about January 1958 to have demonstrated that the reactor would be both technically feasible and economically competitive. At that time, according to the original announcement, a decision is to be made whether to go ahead with construction of the homogeneous reactor, since designated PAR for Pennsylvania Advanced Reactor.

Thus the project may be seen to fall into two phases: Phase 1, scheduled to be completed next year, is to determine that all problems involved are solvable. Phase 2 must solve them.

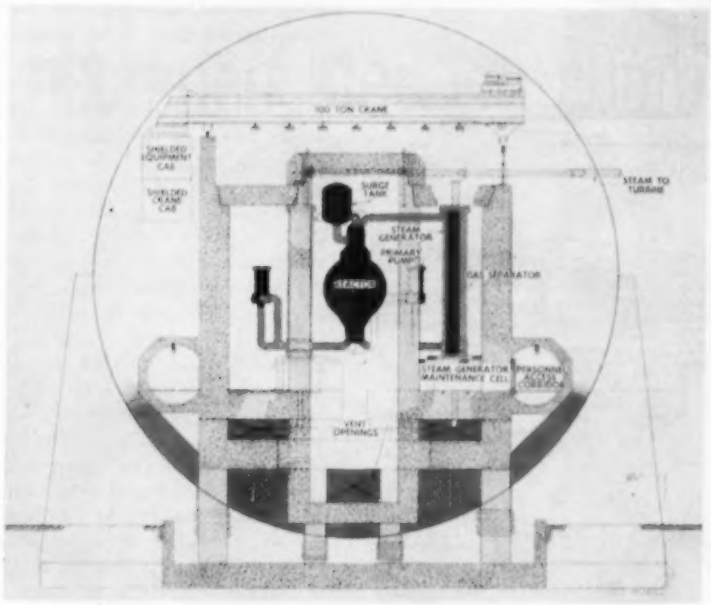
Green Light Seen

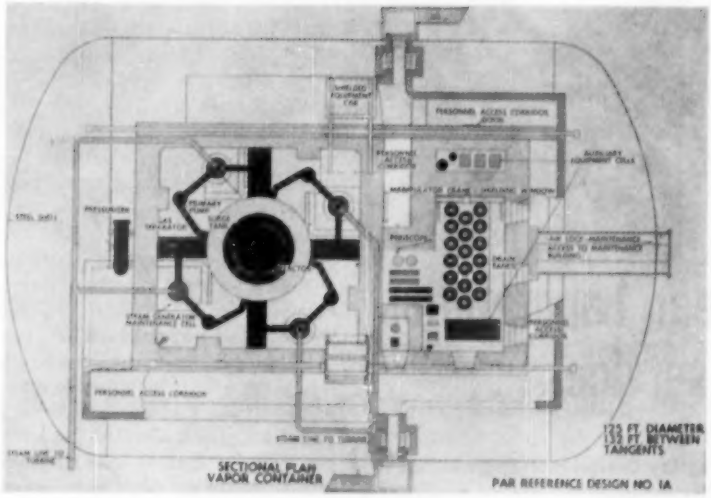
With Phase 1 approaching completion, NUCLEONICS looked into results thus far. In the words of Project Manager W. E. Johnson, "After two years, we have found no technical obstacle that will stop us." Perhaps the most striking discovery made in the course of the development program to date is that corrosion will not be the bugaboo in homogeneous systems that had once been believed.

Full-scale Effort

The fact that PAR is still a developmental, and not yet a construction, project should not lead to the mistaken assumption that it is not an all-out attack on conversion of a laboratory-proven machine to a commercially-exploitable plant.

Staff has grown from 10 engineers and scientists in August 1955, when the project was established, to 85 plus 35 technicians today (of these, 15 engineers and three technicians are PP&L men, the rest Westinghouse). Union Carbide Nuclear Co., third firm in the group for problems of chemical reprocessing, also has a full-time engineer with the project staff as well as several engineers in its New York offices (PAR is the only large plant being studied today in which reprocessing of fuel will





FIGS. 3,4. **Elevation (above) and plan of PAR design shows how concept of limited personnel access is being implemented. Just right of center on plan drawing is manipulator and periscope arrangement for limited maintenance during operation (compare Fig. 8). Grouped around reactor are primary loops, showing use of polar symmetry to simplify replacement of components**

be carried out as an integral part of the plant).

A total in the neighborhood of $5.5-million will have been spent by this year's end on the project, $3–3.5-million of it in 1957. A new 80- × 150-ft building for component testing and development has just been completed adjoining the old Westinghouse Research Lab where the project is housed.

In spite of its advanced, pioneering nature, the project is still close to its original timetable. PP&L still hopes to be able to make the decision early in 1958 to continue with Phase 2.

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thorium slurry type (Figs. 1–4) to be built at an undetermined site in PP&L's eastern Pennsylvania service area. Walter Kidde Nuclear Laboratories is now determining the criteria by which site selection is to be made. (NU, July '57, p. 25.) Initially the PAR group considered both single-region and two-region homogeneous reactors; but to consider them both on equal terms, quite a bit more work had first to be done on the former (since Oak Ridge had already done considerable development work on the latter). So this course was embarked upon; and after one year, when a decision on single- vs two-region type had to be made, the work on the single-region reactor was so encouraging that it was easy to continue. Also the PAR engineers were ready to trade the somewhat better breeding capability of the two-region reactor for the lighter-weight slurries that can be used in the single-region type. Finally, the PAR group takes the view that "we are not building *the* reactor, we're building *a* reactor," and they have not ruled out the two-region type for future interest.

The reactor will put out 550 Mw heat to produce 150 Mw electric net and supply the modest 5% auxiliary load. Plant thermal efficiency will be 27½%.

The reactor pressure-vessel or core tank, according to present designs (Fig. 5) will be 15 ft o.d., of 6-in. carbon steel coated on the inside with ¼-in. stainless; all primary piping will be 304 or 347 stainless steel. Estimated installed cost of the vessel is $1–1.5-million, whence it follows that a spare cannot well be kept in stock. Nor are repairs *in situ* conceivable. Therefore the vessel is being designed for "essentially infinite life"—the designers feel it is worth a fairly high premium to accomplish this. At the same time, the plant design will allow for removal of the core tank if this should, in spite of all advance precautions, become necessary. Stanley C. Townsend, manager of PP&L's atomic power department, remarks that "the delivery time of 30 to 40 months for a new vessel should allow sufficient time for removal of the defective one."

Operating off the core tank will be four primary heat exchanger loops. Each heat exchanger will be a vertical cylinder 39.4 ft high, 6 ft dia, containing 1,550 inverted U-tubes having 9,000 ft² surface area, and an integral steam separator (Fig. 6). Each unit will cost $500,000–750,000, so that stocking of spares again is impractical;

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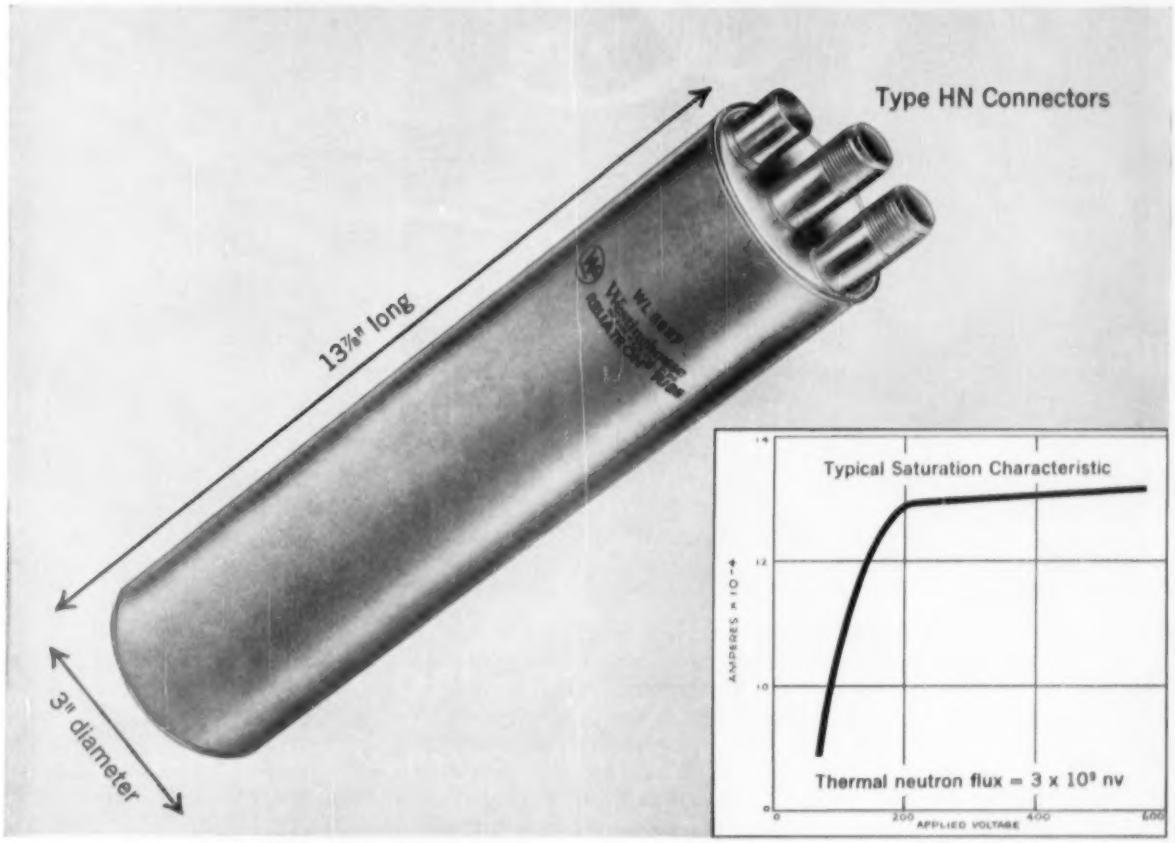

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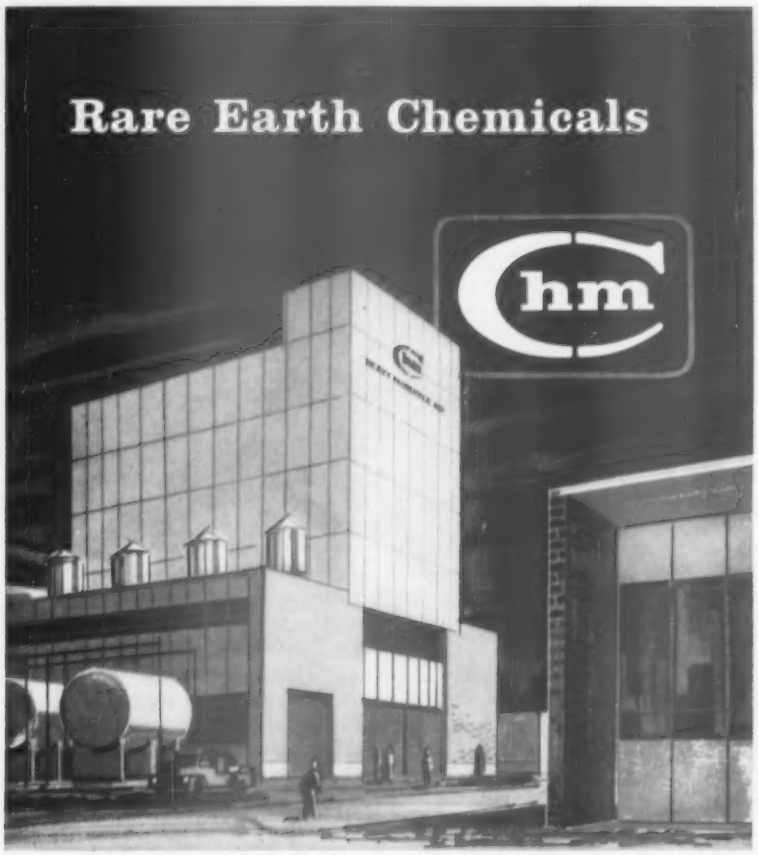

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however, it must be assumed that some tubes may fail in the highly-radioactive circuit, necessitating plugging of the leaky tubes. Therefore the heat exchangers and the over-all plant layout must be designed to permit remote maintenance without prohibitively long shutdowns.

Maintenance Philosophy

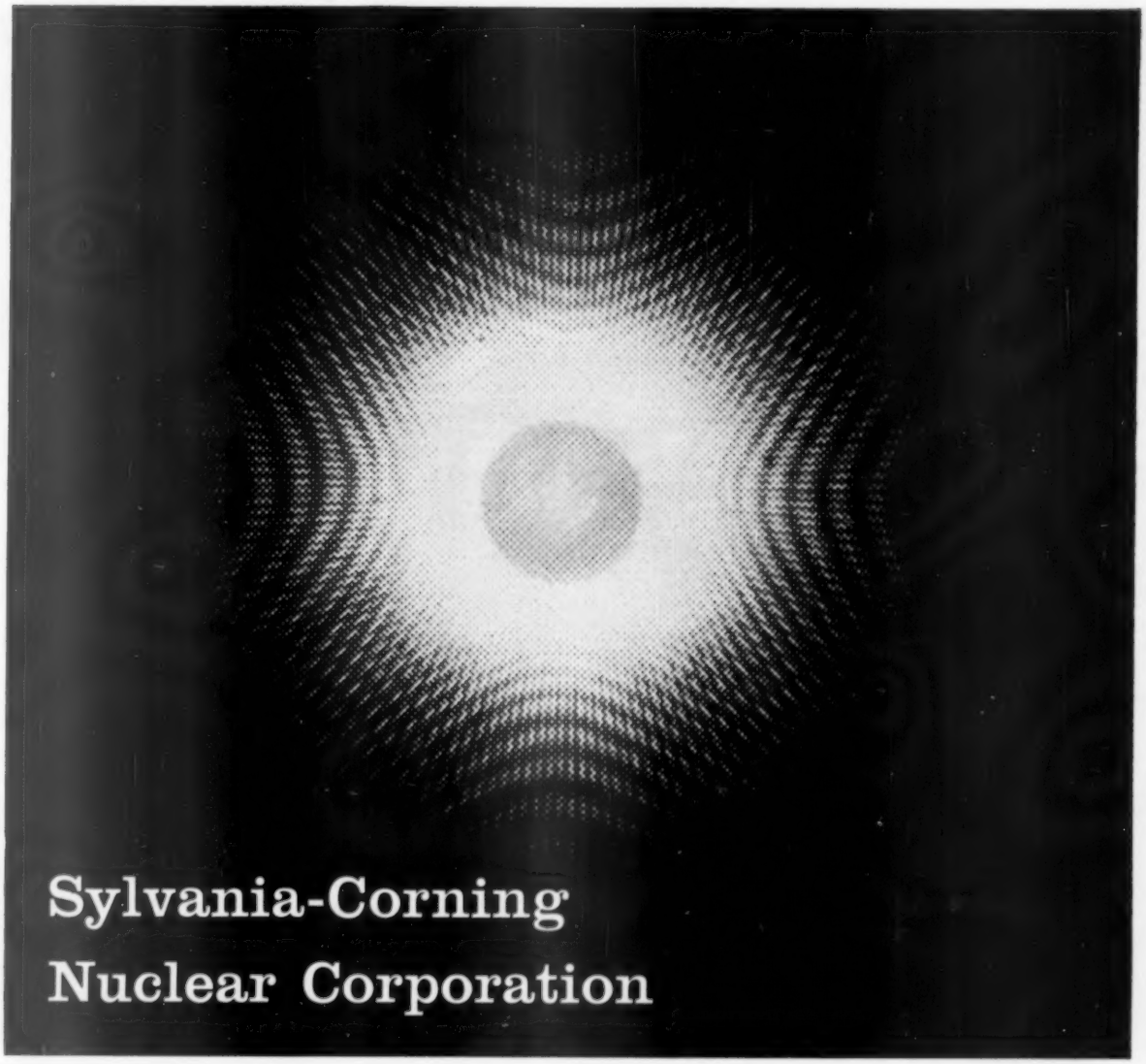
As a matter of fact, plant layout and general maintenance is one of the great-

FIG. 5. PAR reactor vessel as presently conceived is 15 ft o.d. of 6-in. carbon steel with stainless inner lining; cost is put at $1–1.5-million

est problems confronting the PAR group, and has already resulted in the superseding of one complete plant design and its associated concept of maintenance.

Where a conventional plant can tolerate small leaks in the high-pressure system until a convenient time for shut-down and repair, a homogeneous reactor plant obviously must follow even minor leaks by immediate shut-down and depressurization to minimize spread of radioactive gases.

Originally it was contemplated that Oak Ridge's HRT maintenance procedure would be adopted for PAR: flooding the primary compartment and removing affected components with special long-handled tools used with direct viewing. As in the Oak Ridge Homogeneous Reactor Test, it was



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planned to flange and bolt the system using steel O-rings for gaskets. But early studies showed that for a full-scale plant, flanging would not do—that an all-welded primary loop was a must. This in turn required development of a remote process for strength-welding, which on examination proved to be feasible in air but probably not under water. Consequently the concept of underwater maintenance was abandoned and the use of completely remote tools was indicated for dry maintenance of both high and low pressure systems.

The first plant design accordingly called for a concrete cylinder with an inner concentric cylinder of concrete containing the reactor vessel. Piercing the latter are four primary coolant loops including a pair of stop valves, a main coolant pump, a steam generator, a gas separator and a second pair of stop valves. The annular chamber between the two concrete cylinders is divided into six cells: four contain a primary loop each with its associated drain system, the fifth a gas letdown and recombination system and other auxiliary equipment, while the sixth serves as an airlock for passage of equipment between the plant and a separate, adjoining shielded maintenance facility for repair of faulty components.

During operations, the plant container was to be closed to all personnel, and to be operated from a central control station in the turbine plant. Trouble in any of the four loops would result in that loop being shut down by means of its stop valves, the other three remaining in operation. When convenient, the entire plant would be shut down, the shielding blocks in the roof of the cell containing the disabled loop removed, and remote-handling equipment—heavy-duty mainipulators, special jigs, and TV viewing equipment—lowered into the cell for removal and replacement of the faulty component. Leaky tubes in a steam generator would be repaired in place.

New Approach

Although theoretically feasible, this scheme was found on examination to be "far from practical and in any case extremely expensive"; in addition, it began to be clear that the complexities involved in shutting down and isolating one primary loop were formidable.

So the first plant layout design was torn up and an intensive study made to develop a new approach to mainte-

Important data from the U. S. Atomic Energy Commission on reactor problems, techniques, processes, materials, and equipment

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Prepared by a staff of 54 contributing authors

D. J. DePaul, *Editor*

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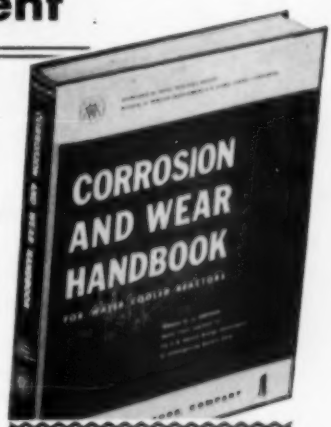

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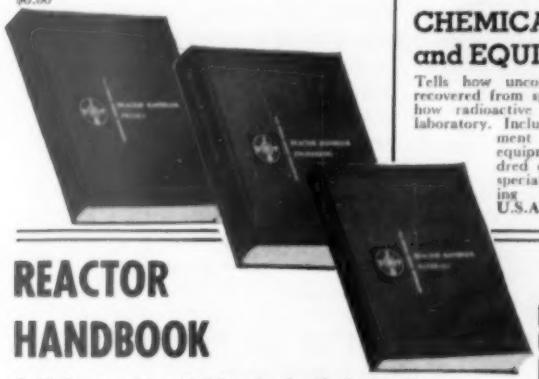

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nance. A new set of ground rules resulted:

- Abandonment of the idea of partial plant operation; elimination of stop valves.
- Compartmentalization of equipment according to type and level of radioactivity.
- Use wherever possible of semi-direct maintenance techniques.
- Modification of the vapor container design, separating it from the biological shielding walls, to permit personnel access in limited areas during operation.
- Increased emphasis on component design to minimize difficulty of maintenance.

A new layout design has been drawn up in accordance with the above specifications (Figs. 2–4). Vapor container is a horizontal steel cylinder, 125 ft dia and 132 ft long. (More recently, Stone & Webster, acting as consulting architect-engineers on the project, say a sphere may be more practical.) Between the container wall and the 7 ft thick concrete biological shielding, personnel access corridors have been designed to permit limited access to some areas of the plant even during full-power operation. A 100-ton overhead crane has a shielded cab that may also be occupied during operations.

Elimination of stop valves allows closer coupling of the entire primary system, and thereby cuts $4-million from fuel and other costs. Another cost-cutting device is that all four loops are designed with polar symmetry: any component may be used as a replacement in any of the four loops, and any special maintenance equipment required likewise may be used on any loop. This contrasts with the first layout, which used mirror symmetry and in many cases required two sets of replacement parts to be carried in stock.

All four main coolant loops are in one compartment, with shielding between them eliminated. Auxiliary equipment is in separate cells, segregated according to radioactivity level expected during maintenance shutdown; also, like pieces of equipment such as drain tanks, instead of being distributed among the primary loops, are grouped together so that special maintenance equipment may be "designed into" that particular area rather than having to be moved from cell to cell as needed, or duplicated in each.

Shielded windows are incorporated in the biological shield so that direct

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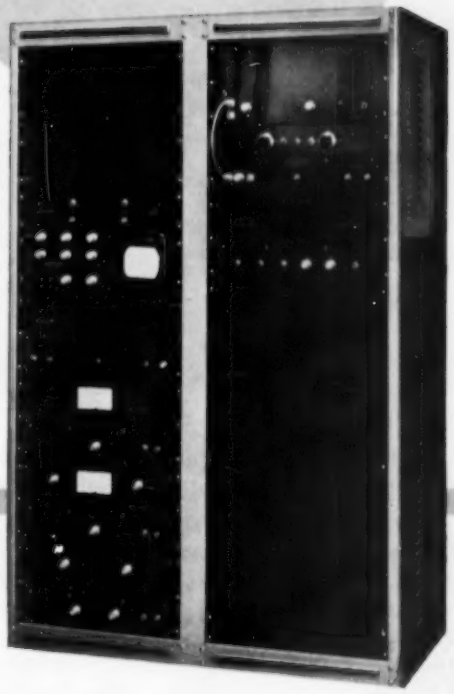

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- Accurate linear cathode ray tube presentation of data during and after measurements.
- Analyzer subtracts or adds at operators option in order to permit automatic background subtraction.
- Precision recording or decimal printed readout which totals every 10 or 100 channels with channel numbers printed directly, 1 to 200.
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- Installation may be done by an RIDL factory engineer at an additional cost.
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viewing from the access corridors is possible.

Using Experience

Thus the basic maintenance approach has been shifted from a completely untried concept to one which—basically similar to high-level hot lab work in which there is already a large reservoir of experience—makes maximum use of existing technology.

Major maintenance tool is the shielded-cab crane, used successfully for remote maintenance in the Hanford chemical reprocessing plants for many years (NU, June '56, p. 66).

Design of the main coolant pumps, "undoubtedly the most vulnerable components in the primary system," has been modified to permit semi-remote techniques to be used for their removal and replacement. The layout permits lowering in place temporary lead shielding around the pump, from behind which a maintenance man can do the work preparatory to removal of the pump using such tools as bolt heaters and impact wrenches. Actual removal, however, as well as installation of the replacement, will be done remotely by the shielded crane, but seal-welding and final bolting operations can be done directly from behind local shielding.

For maintenance of the steam generator, an elaborate mechanism is being designed. This is a periscope-equipped, tool-bearing carriage that penetrates the primary cell shielding wall and the heat exchanger wall itself from a maintenance cell adjoining. It carries master-slave manipulators, leak detection apparatus, and tools for plugging, welding and inspecting a leaky tube (Fig. 8).

Of course, some of the techniques involved in this new design have yet to be experimentally tested, including remote strength-welding and inspection, repair of complicated large-scale equipment, design of special manipulators, etc. This is now being undertaken at a maintenance demonstration facility being installed in the new building at Westinghouse, where the new techniques will be rehearsed on a half-scale loop.

Development Program

The research-and-development program now being carried out in Pittsburgh covers four major areas: slurry-handling, components, systems, and maintenance.

Slurry test loops are the oldest part

Vincent Bicicchi, Pratt Engineer, standing at exterior door of a personnel lock for the Pleasanton, California atomic power plant.

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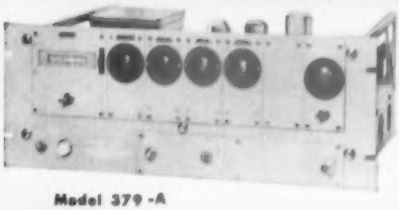

Model 379-A

Developed by H. N. Wilson, ORNL, these Hi-Speed Scalers use a type 6700 Beam Switching tube and permit counting pulses at high rates with extremely low coincidence loss—less than 1% at 10,000 random counts per second. Counting rate on the Model 379—50,000 counts per second. On the Model 379A—500,000 counts per second. Resolving time—Pulse Pairs—on both models is less than 1 microsecond.

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of the project, and by now some 11 of them have been built for various purposes. Two loops, now dismantled, worked on makeup and letdown, to prove the "pumpability" of the slurry and its handling properties. Four 200-gpm loops costing $100,000 each have been doing corrosion testing. Similar to the Oak Ridge slurry loops but with more instrumentation, they consist essentially of a canned-motor pump, heater section, corrosion test specimen holders, pressurizer, and flow-measuring section. They operate at 400–580° F, 800–1,750 psi, pumping slurry at velocities of 85–220 gpm, with the slurry at concentrations of 270–520 gm solid per

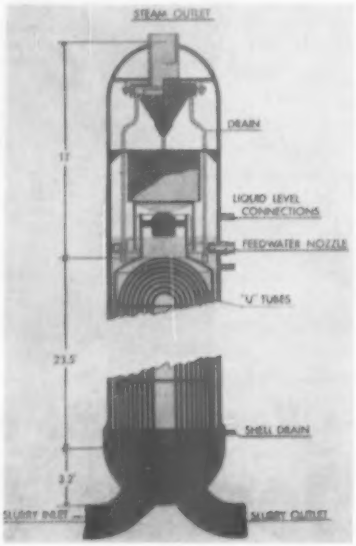


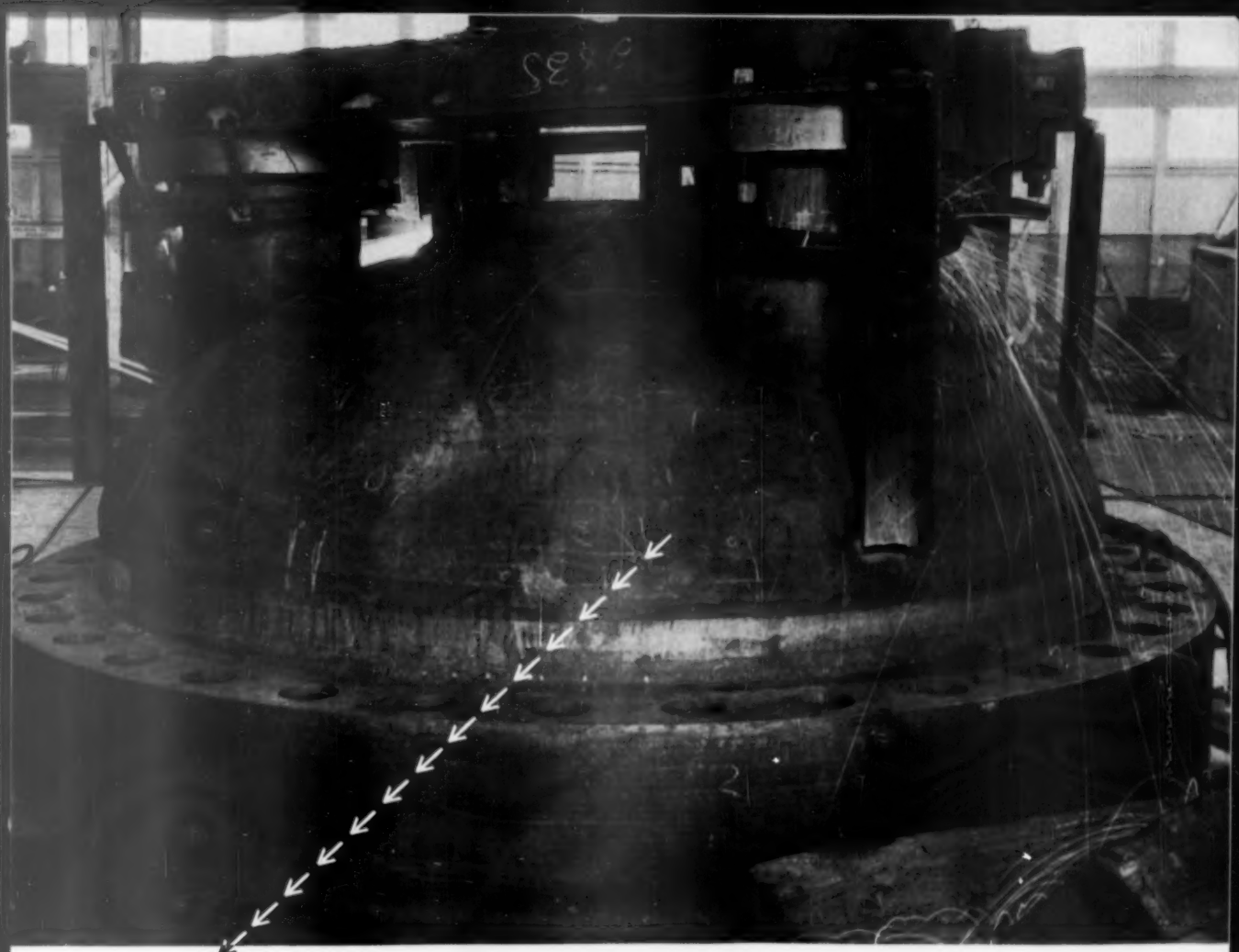
FIG. 6. Cutaway of one of four 9,000 ft² vertical steam generators with integral steam separator; in bottom hemisphere near slurry outlet are tool access openings

liter. The thorium-uranium ratio is 270 parts ThO_2 to 10 parts UO_2. Two of the four loops have been in operation for more than a year and have run more than 10,000 hours, measuring erosion rates at velocities of 8–110 fps although the plant itself will not involve velocities above 50 fps.

Corrosion, Erosion

It was these loops that brought the welcome news that erosion rates are not constant but level off. The erosion rates, which vary with the material and concentration, are very reasonable, Johnson told NUCLEONICS, and are not too much greater than that of water on carbon steel—1–2 mils/yr.

"We can design so that it will be less than 1 mil/yr in the major portions of the plant," he says. "This is more



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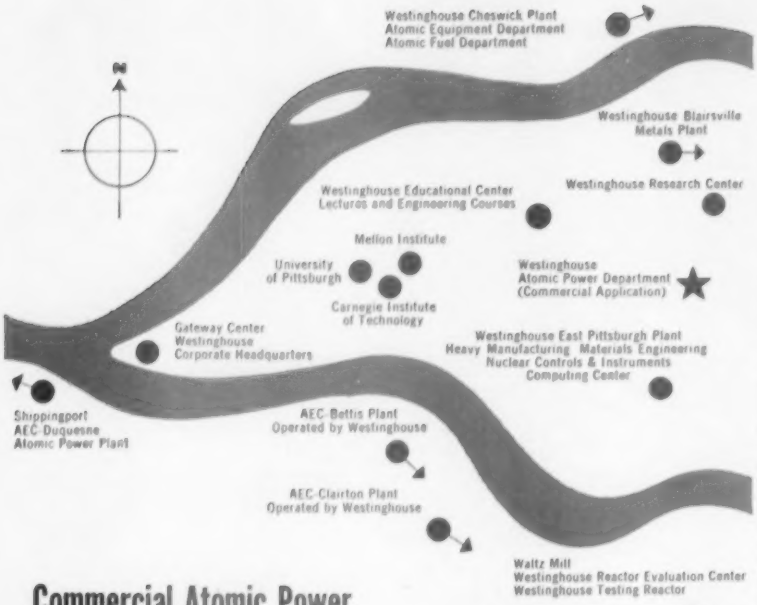

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3. A 134-megawatt reactor for Yankee Atomic Electric Co.
4. A 134-megawatt atomic plant for Edison-Volta, Italian power company.
5. An 11.5-megawatt pressurized water reactor for Belgium.
6. An atomic power plant study for the Carolinas-Virginia Nuclear Power Associates.

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encouraging than we had reason to suspect when we began. Originally we thought that corrosion-erosion was to be our biggest bugaboo. This turned out not to be the case. We found that 100-hr runs are not only meaningless but misleading. You have to run for a long time."

The reason is that after the first 600–700 hr, the incremental attack drops off to only ¼ mil/yr. This is attributed to the fact that the slurry particles break down under the pumping action to, ultimately, <1 micron, and become spherical instead of jagged and abrasive. Once they have been broken down, the erosion-corrosion rate slows down.

To date, work has been with relatively pure slurry. The group is now adding simulated fission products—a test never done before.

Flow Studies

Two low-pressure glass loops are used for flow and for control studies. One, a 1,000-gpm loop, centers about an 18-in. dia lucite sphere simulating the reactor vessel to determine flow distribution and slurry distribution. Pitot tubes closely-spaced along a line from top to bottom measure the pressure at any height on the wall; a probe can move in and read the pressure at any point within. The loop is to determine what must be done to keep the slurry in fairly uniform suspension.

The other loop, of 50 gpm capability, is for studying slurry concentration and control. A commercial centrifuge is also being studied to see how it acts for concentration and control. Like the HRT group, the PAR group wants to achieve shutdown by removing the fissionable oxides and leaving a loop filled with water.

Then there are the in-pile loops that will test slurry behavior under radiation. The first is an operating mock-up, to be followed by several to be installed in the ORR—the Oak Ridge Research Reactor.

The Big One

Finally there is the most glamorous test set-up—Loop D, a $600,000 half-scale mockup of one primary coolant circuit (Fig. 7). It is of 10-in. 304-type stainless steel with 347 stainless flanges, has a 4,000 gpm canned-motor pump, and a 34-ft high, 2-ft-diameter pressurizer. A high-head makeup pump will bring the slurry up from atmospheric pressure to 2,000 psi—design system pressure for the plant itself.

Grinnell is installing the facility, scheduled to go into operation this month. It will contain 500–700 gal, as against 20–22 gal in the corrosion loops, will have high and low pressure systems operating in parallel, will be drained and filled by remote control, and will be equipped with an overhead bridge crane.

Primarily for component development and systems work, it will also be used to verify experimentally the planned maintenance procedures described above. By means of it, jigs and fixtures will be developed for remotely taking out pumps, tearing them apart, replacing bearings, and putting them back together again. Dump tanks, designed as if for an operating plant to be critical-proof (they will thus need a 10–1 length-to-diameter ratio to accommodate the system's fuel inventory, since criticality considerations restrict the tank diameter) are being supplied under the loop, and hot dumps will be made.

Fundamental studies are being carried out on slurry settling properties in such a tank, and propellers are being developed and will be installed to agitate the slurry and prevent settling.

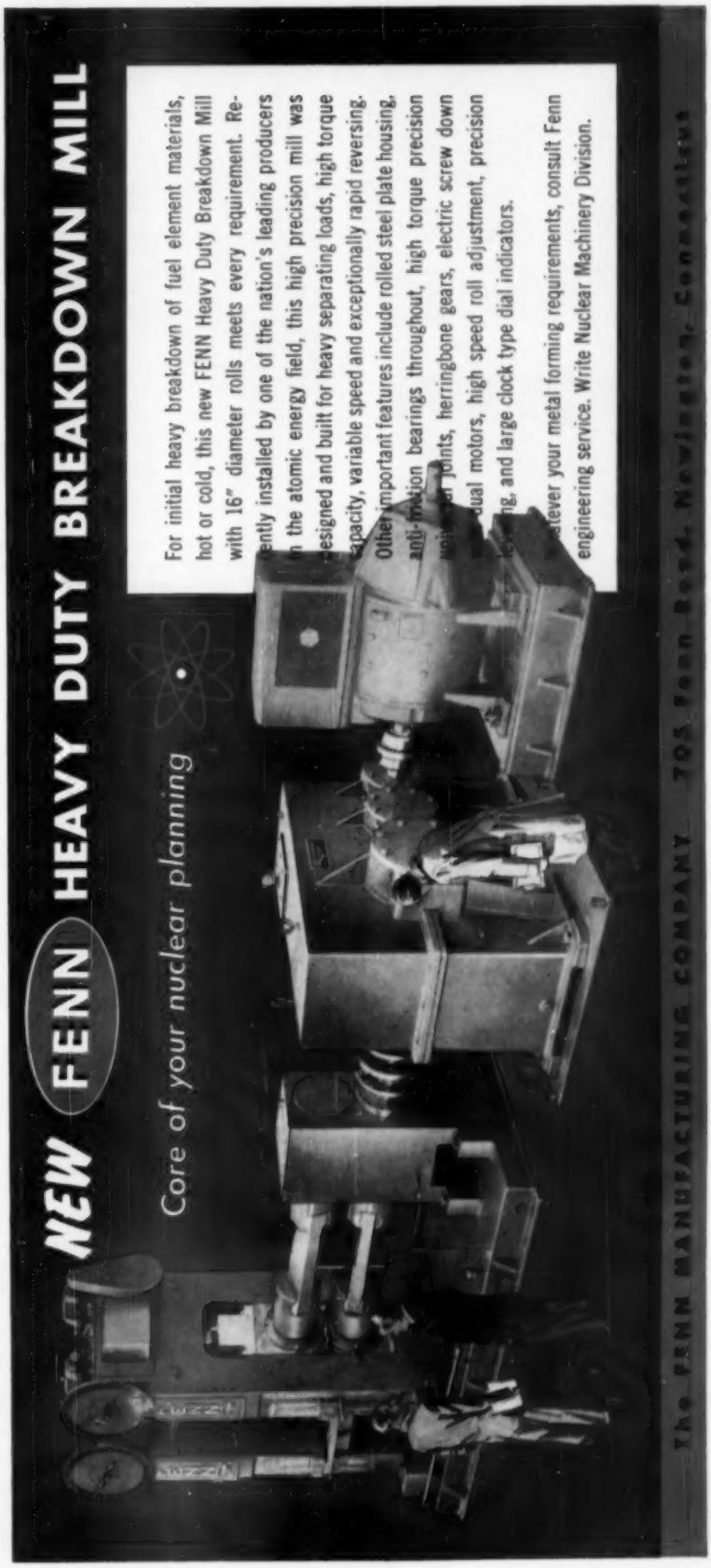
"We're running scared," remarks Johnson; "the propellers are being developed as a hedge. It may be that we will have found by the time the final plant design is made that decay heat will stir the slurry in the dump tanks by convection. But we want to be prepared in either case."

Also in the new maintenance facility building, a mockup of the steam generator remote repair device will be built and tested.

Research Studies

Parallel with this development work, laboratory research is underway on slurries and on reprocessing.

A slurry lab is devoted to small-scale studies on the hydraulics of slurries. It is attempting to aid the design of pipelines carrying slurries by developing the friction factor vs modified Reynolds number. It is trying to determine the minimum rate of flow that will just prevent solids from depositing out—what the group calls the "drop-out flow." It is studying sedimentation rates from room temperature to 300° C. It is determining the two fundamental rheological parameters of non-Newtonian slurries: yield value and modulus of rigidity, as functions of slurry composition and temperature. (*more*)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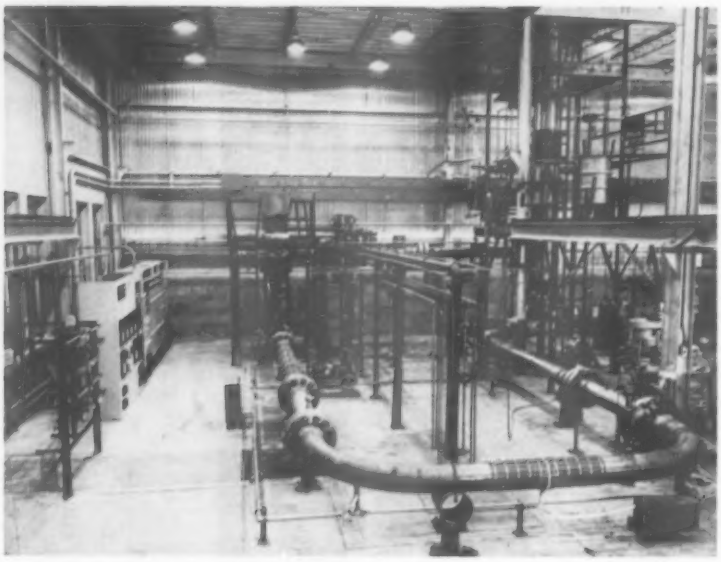

FIG. 7. On August 5, Loop D—the big half-scale loop for demonstrating maintenance procedures—looked like this as it approached completion. Along back wall are main pump, left of center, and pressurizer, at right extending up to roof

A pilot lab for large-scale loops is making studies on catalytic recombination—with hydrogen, at present, and ultimately with deuterium looking ahead to the plant proper, which is to use heavy water. Also being undertaken are some investigations on chemical reprocessing.

A slurry preparation lab has as its main task making up the huge batches of slurries required in the test loops, but is also used for some physical

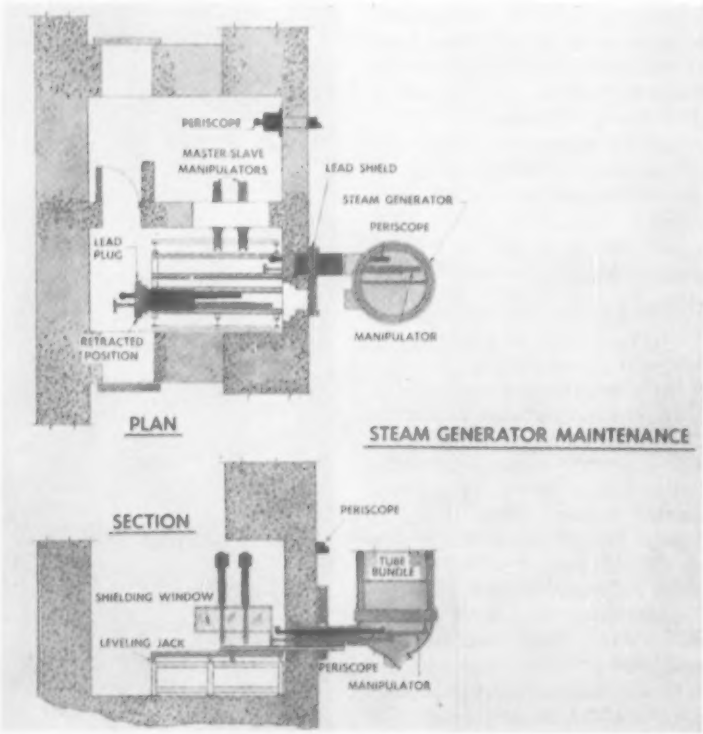

FIG. 8. Carriage bearing periscope and tools that penetrates primary shielding wall to enter heat exchanger shell for working on defective heat-exchange tubes, including facilities for plugging and welding a leaky tube

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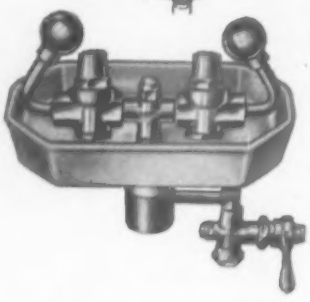

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chemistry. For example, it is trying direct denitration of $Th(NO_3)_4$ and $UO_2(NO_3)_2$ to the corresponding oxides, ThO_2 and UO_3. It is also working with loop-pumped materials to simulate operating conditions (except for fission products).

Slurries are being tested in mixtures ranging from 250 to 500 gm/liter ThO_2 with from 10 to 27 gm/liter UO_3; optimum now seems to be 270–10. The uranium will be fully enriched in the operating plant. Unity conversion ratio is the goal, but "we may want to design for less than unity although probably more than 0.95," Johnson told NUCLEONICS. "We are trying for the best mills/kwh conditions, and it may be that the last 0.05 would cost us money. We don't think there is anything holy about a unity conversion ratio—what we do think is holy is mills/kwh."

Costs: Capital . . .

Capital cost of the plant itself, exclusive of the developmental budget, was placed at about $40-million, but as with all other power reactors (NU, March '57, p. R5) costs have been rising. A re-evaluation is now under way to determine how much. The study program will also have an effect on costs. For example, power density at the first thermal shield inside the reactor vessel has been conservatively estimated; if it can be increased, the vessel size can be decreased. Specifications for the vessel are to be completed by year's end.

. . . and Operating

Preliminary estimates of operating costs appear to be in the range of 9–12 mills/kwh at the switchboard. The principal uncertainties at this time are maintenance costs and the downtime required. Included in the above cost range is the cost of reprocessing, estimated at 1–2 mills/kwh.

PP&L's system average in 1955 was on the order of 7 mills/kwh.

As David H. Fax, assistant PAR project chief for Westinghouse, sums up, "While in many areas we don't yet have the detailed design information on which to build a plant, we have uncovered no area where we are afraid we won't get it in time. We do have a much better feel for the range of information we need, and are confident that we will get it. The corrosion problem is a good example of the way problems work out under attack."

Calculating Spatial Distribution of Reactivity Coefficients

By HENRY E. STONE
Knolls Atomic Power Laboratory, General Electric Co., Schenectady, New York

In studying the transient behavior of reactors it is often necessary to calculate the variation of the reactivity with time caused by transient temperature variations in the core. (The study of cold-water accidents in water-cooled reactors is an example.) A calculation of this kind requires both a knowledge of the transient temperature distribution and the "spatial distribution" of the temperature coefficient in the reactor. The temperature distribution, which can be expressed, for example, as the temperature deviation $T(v,t)$ from the zero-time temperature, can usually be determined as a function of position and time from heat-transfer and fluid-flow studies. If the temperature coefficient per unit volume $k'(v)$ is also known as a function of position within the reactor then the reactivity as a function of time is given by

$$\Delta k(t) = \int_V k'(v)T(v,t)dv \qquad (1)$$

where V is the entire reactor volume.

We will explain how to determine the function $k'(v)$ for a reactor from the fluxes provided by a multigroup calculation. While we will refer explicitly to the problem of determining the temperature-coefficient distribution, the method is equally applicable for predicting density- and material-reactivity-coefficient distributions.

Basic Idea

Reactivity calculations by the multigroup treatment of diffusion theory are described in (*1*). For a three-group application, this treatment results in the following equations:

$$\begin{aligned} D_1\nabla^2\phi_1 - \Sigma_{s1}\phi_1 + \nu\Sigma_{f1}\phi_2 + \nu\Sigma_{f1}\phi_3 &= 0 \\ D_2\nabla^2\phi_2 - \Sigma_{s1}\phi_2 - \Sigma_{s2}\phi_2 + \Sigma_{s1}\phi_1 &= 0 \\ D_3\nabla^2\phi_3 - \Sigma_{s2}\phi_2 + \Sigma_{s3}\phi_3 &= 0 \end{aligned} \qquad (2)$$

where D is the diffusion coefficient, Σ_{s1} the macroscopic slowing-down cross section, Σ_a the macroscopic absorption cross section, Σ_f the macroscopic fission cross section and ϕ the fluxes.

Subscripts refer to energy groups: 1—fast, 2—epithermal and 3—thermal. The constant ν represents the number of neutrons produced per fission.

The solution of this set of equations for a particular system gives the multiplication constant k for the system.

The effect on k of changes in reactor structure or composition resulting, for example, from temperature changes or localized material substitutions is most readily determined by means of perturbation theory* (*1, 2*). The total change in reactivity due to a change in some independent variable (such as temperature) can be thought of as the sum of the contributions arising from the changes induced in the four basic constants (D,Σ_f, Σ_a and Σ_{s1}) in Eqs. 2. We are interested in finding $d^2k/dVdT$, the reactivity coefficient per unit volume, as a function of position within the reactor. If this quantity is represented by k' then we can write

* In this treatment the set of multigroup equations is represented by a matrix equation of the form $\mathbf{M}\phi_i = \lambda\phi_i$ where $\mathbf{M}$ is the matrix operator and λ is the eigenvalue (actually the reciprocal of the reactor period). The adjunct matrix $\mathbf{M}'$, obtained by interchanging the rows and columns of $\mathbf{M}$, can be used to define a new set of fluxes m_i:

$$\mathbf{M}'m_i = \lambda m_i$$

Since the m_i are eigenfunctions of $\mathbf{M}'$ they are known as the adjoint fluxes. It follows that the adjoint fluxes and the original fluxes satisfy the following relationship:

$$\int m\mathbf{M}\phi dv = \int \phi\mathbf{M}'mdv$$

Physically the adjoint fluxes represent the "worth" of a neutron in producing fissions as a function of position in the core. For example, a neutron is worth more in the center of the core than in the reflector; hence the adjoint fluxes will be greater in the center than in the reflector.

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$k' = k_1 + k_2 + k_3 + k_4$ to take into account the four independent contributions. Perturbation theory (*2*) gives the following expressions for these contributions

$$k_1 = \sum_i \chi_i m_i \sum_j (d\Sigma_t/dT)_j \phi_j / N$$

$$k_2 = -\frac{1}{\nu} \sum_i (dD/dT)_i \nabla\phi_i \cdot \nabla m_i / N$$

$$k_3 = -\frac{1}{\nu} \sum_i (d\Sigma_a/dT)_i \phi_i m_i / N$$

$$k_4 = -\frac{1}{\nu} \sum_i (d\Sigma_{sl}/dT)_i \phi_i (m_i - m_{i+1}) / N$$

where $N = \int_V \sum_i \chi_i m_i \sum_j \Sigma_{tj} \phi_j dV$

and χ_i is the fission spectrum or the fraction of neutrons produced in a certain energy group i, ϕ refers to the flux and m to the adjoint flux, V refers to the volume of the entire reactor including reflector regions and the summations are performed over all energy groups.

- k_1 is the change in reactivity caused by changes in the fission cross section. For ordinary reactors $d\Sigma_f/dT$ is negative, the cross section decreases with an increase in temperature and its reactivity contribution will be negative, that is, it will result in a negative temperature coefficient.
- k_2 is the reactivity change due to diffusion-coefficient change. The gradient of the fluxes $\nabla\phi_i$ is proportional to the leakage of neutrons and k_2 is therefore the contribution to the temperature coefficient due to leakage of neutrons. Since $D = 1/3\Sigma_{tr}$ and $d\Sigma_{tr}/dT$ is negative, dD/dT will be positive so that k_2 normally is negative.
- k_3 shows the effect on k' of changes in the absorption cross section. $d\Sigma_a/dT$ is usually negative which together with the minus sign is responsible for a positive contribution to the temperature coefficient. Usually Σ_a and Σ_f vary in the same proportion so that k_1 and k_3 often times are similar in magnitude but opposite in sign and may cancel.
- k_4 shows the contribution of the change in slowing-down cross section $d\Sigma_{sl}/dT$; Σ_{sl} is proportional to D, the diffusion coefficient, and inversely proportional to τ the age of the neutrons (*3*). $d\Sigma_{sl}/dT$ is therefore a more complicated term involving dD/dT and $d\tau/dT$ but is normally negative and results in a negative temperature coef-

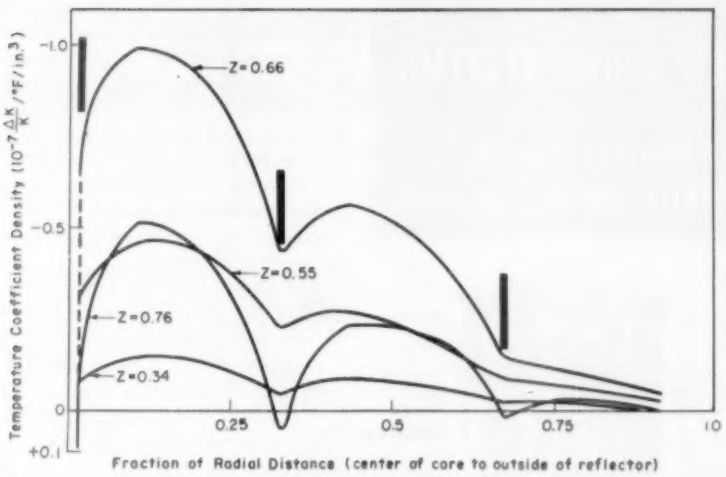

FIG. 1. Temperature coefficient per unit volume, $k'(r,z)$, as function of radius and axial position in pressurized-water reactor. Z = fraction of reactor length (core plus end reflectors) measured from bottom. Black bars mark radial positions of control rods. Rods extend into reactor from top for 29% of reactor length

ficient because of the negative $(m_s - m_{s+1})$ term. k_4 can be the most important term if k_1 and k_3 cancel each other.

As written, the expressions give the *temperature* coefficient per unit volume; as noted earlier, they could just as well be used to find the reactivity-coefficient distribution for any other variable (e.g., density or composition). One has only to replace the temperature derivatives with derivatives of the variable of interest. The above formulation also allows the four reactivity effects to be evaluated separately.

Sample Problem

The above method was used to find the temperature-coefficient distribution for a cylindrical pressurized-water reactor in connection with a cold-water-accident study. The fluxes were obtained by solving the multigroup and adjoint equations for a cylindrical model having azimuthal symmetry. A two-dimensional (R-Z) reactor calculation was performed on the UNIVAC with a 38×29 mesh; the control-rod regions were approximated by nuclear-poison annuli.

Once the fluxes are known, the ex-

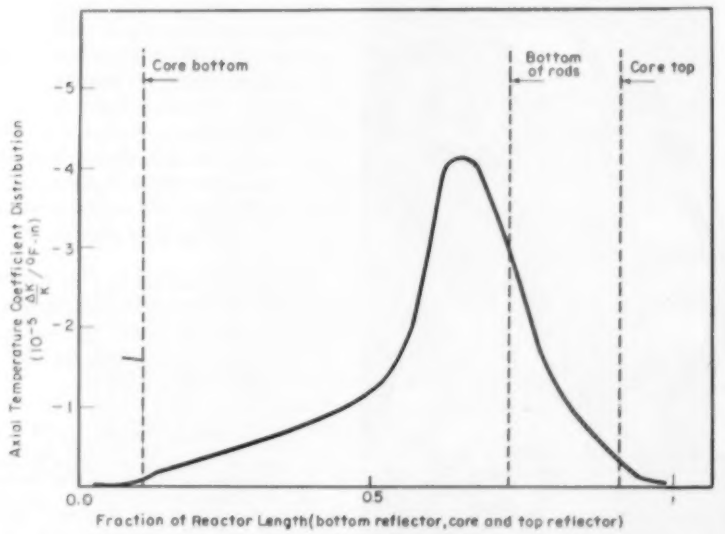

FIG. 2. Axial variation of temperature coefficient (after integrating out r dependence) shows region just below control rods is most sensitive

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pression for k' can be used to calculate the reactivity coefficient per unit volume at each of the two-dimensional mesh points used in the multigroup calculations. The final results giving $k'(r,z)$ as a function of position in the reactor are shown in Fig. 1. The plots can be used to ascertain the worth of the temperature coefficient in various regions of the core to predict transient behavior of the reactor.

For example, in cold-water accident studies of a water-cooled reactor, one is interested in the rate of travel of the cold water wave. Some water in the core may be essentially stagnant and may depend for its cooling rate on heat-transfer mechanisms. Taking these things into consideration one can approximate the temperature change with time at points throughout the reactor by some function $T(r,z,t)$. The total reactivity change of the system as a function of time $\Delta k(t)$ is then given by Eq. 1 and is simply the integral of the product of k' and T.

$$\Delta k(t) = \int_V k'(v)T(v,t)dv$$

Figure 2 shows the axial distribution of the temperature coefficient obtained by integrating $k'(r,z)$ over the radius r. It may be noted that the peak in the temperature coefficient occurs in the region with a high k, namely, the nonpoison region just below the control elements. The temperature coefficient falls off in the control-element region on the top; near the bottom its reduction is due to the lowered k in this location.

It should be noted that these results are for a clean reactor at operating temperature and pressure with steady-state xenon. The temperature coefficient and its spatial distribution depend on reactor condition, hours of operation, rod positions, reactor materials, xenon activity and reactor temperatures and pressures and a change in any or all of the above can result in different results than are shown in Fig. 1 and 2.

The above method can be used to establish reactivity coefficients of various materials within the core and to determine void coefficients due to local boiling within a reactor.

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"Metallo-Organic" Polymers–Possible Fuel Materials

By A. J. RESTAINO
Nuclear Division, The Martin Company
Baltimore, Maryland

Polymers of mono- and dicarboxylic acids with uranium chemically bound in may prove suitable as nuclear-reactor moderator-fuel materials. Promising properties (Table 1) are high values of N_H (number of hydrogen atoms per cubic centimeter), excellent heat and radiation stability and complete homogeneity even at maximum metal content. Polymers containing lead or lithium in place of uranium may be useful shielding materials.

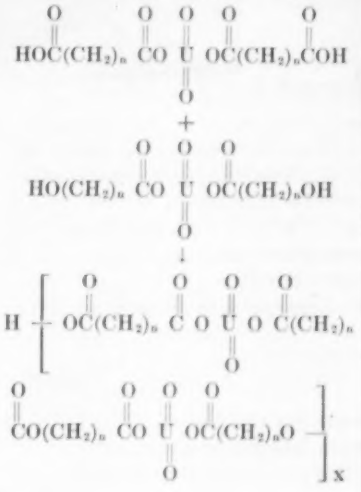
Polymer Preparations

Organic polymers containing metals have been previously synthesized (*1–3*). However, metal polymers formed by chelation are limited to certain metals, and metal chelates formed from carbonyls or carboxyls and polyacrylic acid salts (*4*) are further limited in radiation applications since they lack radiation stability. Although molecular weights of chelate polymers are generally low, phthalocyanine-polymer chelates of copper (II) can be prepared in molecular weights above 20,000 (*5*).

Heteropolymers of molybdenum have been prepared with molecular weights generally below 3,000 (*3*). However, they degrade in strongly acid or basic media.

Certain metallo-organic polymers may also be prepared through the solid-state reaction of their acrylate salts (*1, 6*). Table 2 summarizes the initial rates of polymerization of these salts through gamma irradiation. These polymers are negatively birefringent, which indicates that the propagation reaction occurs along preferred crystallographic directions. The difference in polymerization rates given in Table 1 may be attributed to differences in crystal form. The crystal forces are probably almost entirely responsible for polymerization since acrylic acid will not polymerize in basic solutions (*7*), presumably owing to electrostatic repulsion of free radicals and the acrylate monomer.

The polyacrylic salts considered so far contain the metal as part of the polymer side chain. Conceivably, divalent-metal polymers may be prepared through a condensation polymerization to yield high-molecular-weight compounds containing the metal as an integral part of the main chain. The reaction in the case of uranium would be as follows

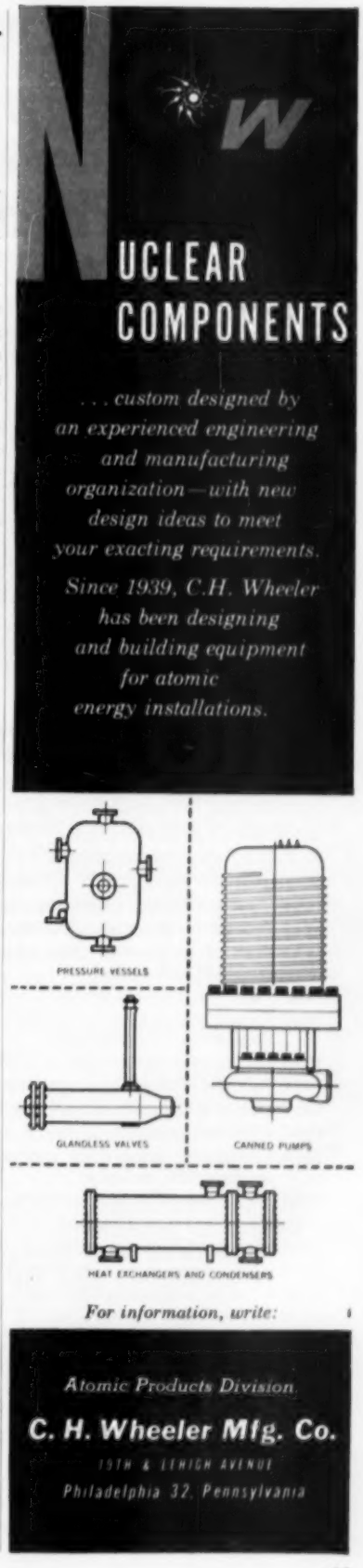


Care must be exercised in choosing the mono- and dicarboxylic acid since there will undoubtedly be values of n for

TABLE 1—Properties of Metallo-Organic Polymers

Polymer	*% metal*	*% carbon*	*% oxygen*	*% hydrogen*	*% sulfur*	*Density (gm/cm³)*	$N_H \times 10^{-22}$	*Softening point (°C)*
Uranium	12.92	70.65	5.50	8.99	1.92	1.36	7.35	310
Uranium	15.35	66.94	6.78	8.51	2.44	1.41	7.22	310
Uranium	39.0	46.50	9.10	6.10	2.50	1.61	5.90	310
Lithium	1.15	85.3	2.07	10.1	1.38	1.03	6.30	280
Lead*	13.92	71.70	3.75	8.83	1.78	1.32	6.97	310

* Specific heat = 0.42 cal/° C/gm; water absorption = 0.019.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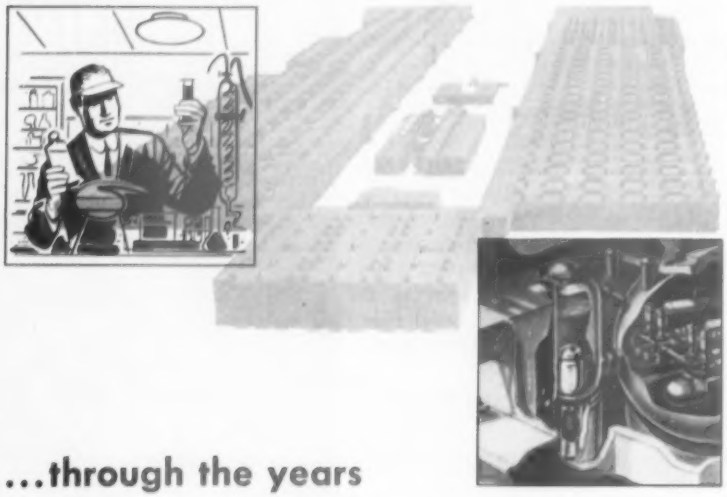

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Notable dates in this chronology of nuclear progress include:

1917 First production, processing and use of uranium.
1942 Production of uranium for first atomic bombs.
1942 Start of design and construction of gigantic gaseous diffusion plant (K-25) at Oak Ridge.
1947 First uranium recovery from reactor wastes.
1948 Design and engineering of plutonium reactor, production and separation facilities for Hanford.
1950 Design of decontamination and waste disposal systems.
1951 Establishment of large uranium ore mill and refinery.
1951 Design and engineering of thermonuclear production facilities.
1954 Entry into uranium mining.
1954 Consulting, engineering and design for Con Edison nuclear power station (AEC permit #1).
1954 First study of reactor fuel reprocessing problems for the AEC.
1955 Entry into field of thorium, rare earths and heavy minerals.
1956 First foreign nuclear contract: Heavy Water Plant for India.
1956 First solvent extraction method for uranium processing.
1957 First large European contract: 140,000 KW nuclear power station for Italian Government.

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TABLE 2—Polymerization Rate

Monomer	*Initial polymerization rate (% conversion/hr)*
Potassium acrylate*	56.8
Calcium acrylate*	18.1
Barium acrylate*	75.1
Uranyl acrylate†	0.65

* Gamma-irradiated at 190,000rep/hr.
† Gamma-irradiated at 300,000 rep/hr.

which cyclization may result, which will tend to minimize polymer formation.

We are now studying a technique for synthesizing organo-metallic polymers in which the starting material is a preformed polymer. The initial polymer is chosen for its radiation stability.* A second material, also radiation resistant and capable of adding acid groups, is grafted to this polymer by means of gamma irradiation. This graft copolymer is then treated with acid and subsequently with a metal hydroxide to produce the metal polymer (*8, 9*).

The technique allows preparation of organic polymers with a wide variety of metals. The metals are chemically bound into the polymer, which makes the system homogeneous. Polymers of uranium, lead, lithium, iron and combinations thereof have been prepared, and some of their physical properties have been evaluated. The interest in the lithium polymer is based on the fact that Li^6 undergoes an (n,α) reaction, reducing the gamma-shielding problem.

The composition of these polymers can be adjusted so that the weight ratio of metal to hydrogen and metal to carbon can be significantly varied. The weight composition of metal can be as high as 60% for the heavier metals. The addition of metals such as cadmium, aluminum, thorium and others is also possible.

Polymers of lead, iron and uranium, with as little as 1% by weight of the metal, have softening points† above 310° C. This is presumably due to metal-ion crosslinking, which may occur with divalent or trivalent metals. The monovalent lithium polymer has a lower softening point than that of the divalent metal polymers.

To determine the effect of metal type and percent composition on the tensile

* Unless otherwise specified, radiation stability is based on tensile-strength changes upon irradiation.

† These polymers decompose without melting in the neighborhood of 390° C.

TABLE 3—Mechanical Properties

Polymer	*% metal*	*Tensile strength (psi)*	*% elongation*
Initial	0.00	1,430	>400
Lithium	1.1	1,710	68.5
Lead	2.6	2,680	39.0
Lead	5.7	2,280	22.0
Lead	12.0	2,620	17.5
Lead	15.0	3,020	15.0
Lead	18.0	3,200	4.0

* Testing rate 1 in./min.

strength and elongation of the metal-organic polymers, several compositions of lead and lithium were studied with a BTE tension test machine. The results are compared in Table 3 with preformed nonmetal polymer. The tensile strength of the lead polymer appears to increase with increasing amounts of lead. On the other hand, percent elongation decreases significantly at the higher lead compositions. In the case of the monovalent lithium-ion polymer, the tensile strength is less and the elongation greater than the divalent lead polymer of comparable mole ratio. These facts are consistent with the higher softening point of the divalent-metal polymers and is probably due to the metal-ion crosslinks.

Based on tensile-strength studies, the radiation stability of the metal polymers appears to be better than 10^{19} nvt. The G-value for gas formation for these materials is 1.42 molecules per 100 ev. Other data are summarized in Table 1.

Heat-transfer studies as well as detailed studies of fission-product formation and elimination are required if the uranium polymer is to be considered for use as a homogeneous moderator-fuel element. Further studies are in progress to evaluate the shielding ability.

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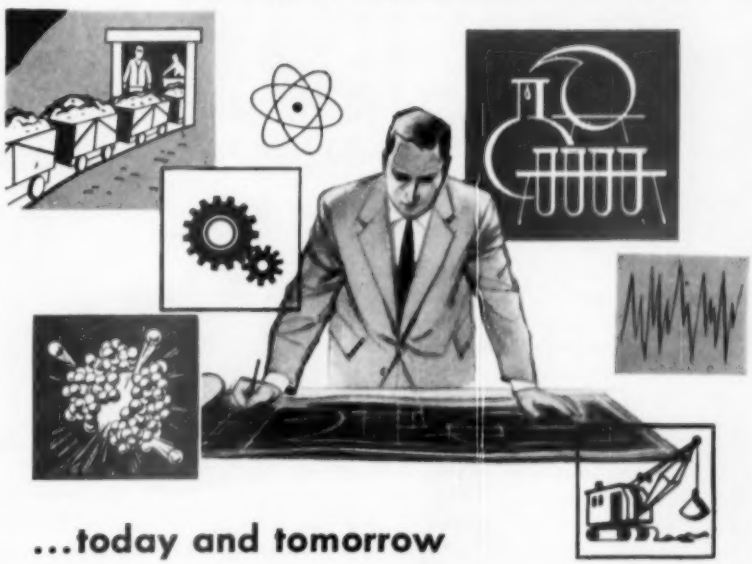

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APPLIED RADIATION

How Cheap Can Isotopes Become? The economic worth of a process using a radioisotope usually depends on what the isotope costs and what it will cost in the future. Usually we know the current AEC selling price, and we know that it will come down emphatically if isotopes are produced in increased volume. But Commissioner Libby of the AEC defined another set of helpful figures in a recent speech at Hazelton, Pa. He offers a formula for computing the minimum that an isotope price will approach as production volume is increased without limit.

The AEC finds that neutrons can be produced and put into a target at a cost of $4 per milligram of neutrons. Chemical separation of the product isotope can be performed for $3 per milligram of absorbed neutrons—on the average. Using the sum of these figures—$7 per milligram of absorbed neutrons—as a starting hypothesis, we get rock-bottom prices for typical radioisotopes as shown in the table.

	Prices ($/curie)	
Isotope	*Present*	*Rock-bottom*
Neutron-produced, non-transmuted		
Co^{60}	2–5	0.06
Neutron-produced, transmuted		
H^3	2	0.25
C^{14}	22,000	110.00
S^{35}	2,000	0.005
Fission products		
I^{131}	550	0.0004
Cs^{137}	10	0.30

In the case of fission products, the same $4 per milligram is the cost of neutrons causing fission. Thus one uses fission-product tables and assesses the cost of the appropriate fraction of a neutron to each atom of a radioisotope produced instead of using one neutron per atom as we do for the other types of production. The processing cost per milligram of neutrons absorbed is still $3. Some modification is in order where chemical separation techniques are particularly difficult.

The higher costs currently charged are influenced primarily by two factors: (1) Sales are still very small compared with the reactor production on which the $7 figure is based, and (2) large-volume isotopes currently carry some of the costs of small-volume ones.

Soft Betas Extend Light-Source Life Self-luminous surfaces have come a long way from radium watch dials. At least two manufacturers are making devices that can be used for illumination, calibration, or signalling. All of them use soft-beta emitters to excite a phosphor.

The big advantage of low-energy beta excitation is that it does not damage the phosphor appreciably. Older sources lost their luminosity in a short time because of this type of damage. The ones now made decay only as the radioisotope does.

The prototype demonstration lamp shown in the upper photograph is visible at a distance of 500 yards according to its manufacturer, the United States Radium Corp. It contains a Kr^{85}-excited light source that has a green, yellow, or orange-red phosphor. Cost of a single unit is $115; quantity prices are estimated at $35–75 each.

The Atomlight sources manufactured by the New England Nuclear Co. are excited by tritium and made with blue, green, orange, and red phosphors. (See lower photograph.) They come in three sizes. The smallest is 1.75 in. in diameter and 0.563 in. high; largest is 2.5 in. in diameter and 2.5 in. high. Prices are $80–150.

U. S. Radium light, 8 in. long, 10 lbs

Both manufacturers make several types of self-luminous devices. Some U. S. Radium sources attain brightnesses in excess of 1,000 microlamberts (1 lambert = 1 lumen/cm^2). Their early sources of 3–5-in. diameter permitted a person with normal vision to read a newspaper in total darkness with the lamp 4 in. from the surface. Later models use an improved optical system and permit reading at normal distances with the light at arm's length from the page. New England Nuclear Co. supplies sources of 20–800-microlambert brightness.

New England Nuclear's 2-in.-long light

In addition to the 10.4-yr gaseous Kr^{85}, U. S. Radium uses several other beta emitters in self-luminous sources for particular purposes. Gaseous tritium and Kr^{85} produce the brightest ones. Sr^{90} decays more slowly, but it requires more shielding because of the 2.2-Mev beta of the daughter Y^{90}. C^{14} with its long half-life (5,600 yr) is appropriate for stable, very-low-intensity calibration sources. Short-half-life Tl^{204} and Pm^{147} (when available) are used in sources of medium brightness where the amount of shielding necessary with Sr^{90} is undesirable. Tritium, requiring minimum shielding, is used in small, lightweight, low- to-medium-level sources requiring the ultimate in compactness.

Sealed Tube Makes 10^8 Neutrons/Sec Shown in the photo on page 194 is a high-intensity neutron source only 1 ft long and $1\frac{3}{16}$ in. in diameter. It is a sealed ion-accelerator tube capable of producing 10^8 neutrons/sec. Primarily it is designed for oil-well inspection or "logging," but it is easy to imagine its use as a copious supply of neutrons in reactor startup, as the exciter in analytical devices based on neutron-activation analysis, and in experiments that require pulsed point sources of neutrons.

Operated at 60 kv the new device produces 10^7 n/sec, and at 100 kv, 10^8 n/sec. It is mounted with its own high-potential supply in a 3-in.-diameter logging device that can be lowered into bore holes, and it has already been tried out in test wells. The development was carried out by W. R. Arnold, A. H. Frentrop, H. A. Mehl-

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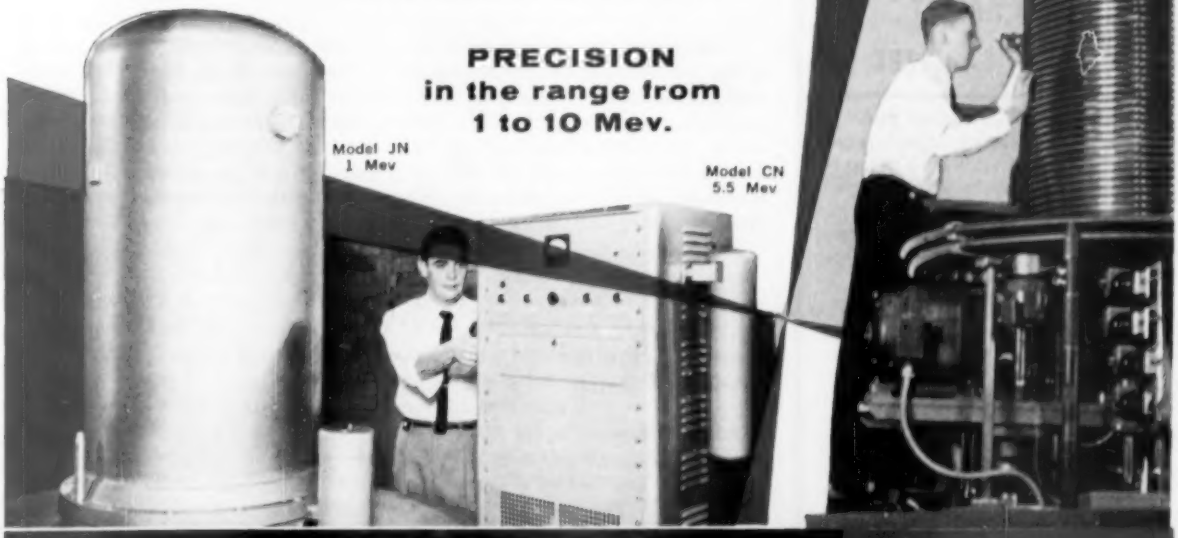

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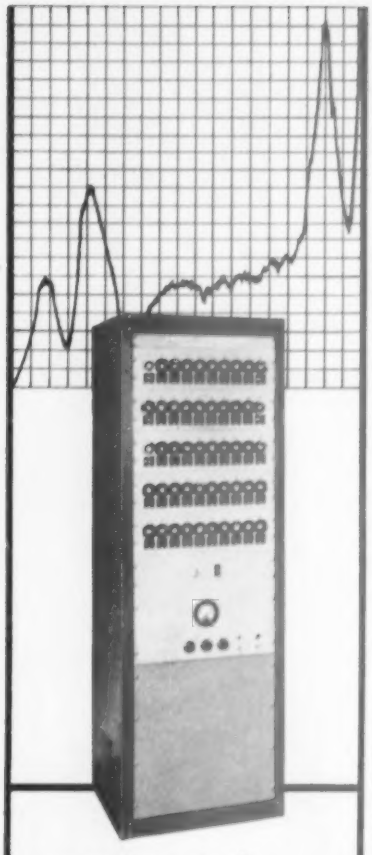

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APPLIED RADIATION *(Cont.)*

horn, D. C. Moore, H. Sherman, S. Soloway, and M. Ferré of Schlumberger Well Surveying Corp.'s Ridgefield, Conn., laboratories.

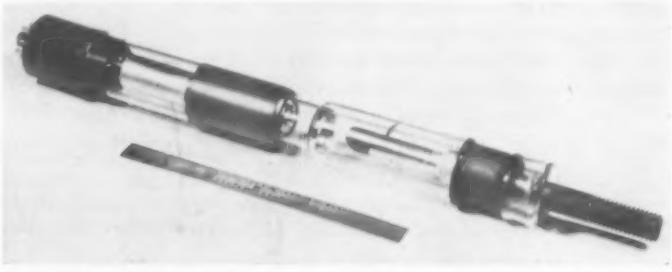
Little in the way of technical detail has been released by Schlumberger. However, one can conjecture that deuterons are supplied from a heated ZrD source, ionized in a discharge, accelerated by the high potential, and caused to strike a metal target with tritium absorbed in it. Vacuum could be maintained in the sealed-off accelerator tube by means of getters.

Deuterium-tritium collisions produce 14-Mev neutrons through the reaction

$$D + T \rightarrow He^4 + n + 17.7 \text{ Mev}$$

The He^4 nucleus takes away the energy that is not allotted to the neutron. The cross section for the reaction has a small value at 10 kev and rises sharply to a peak of $\sim$5 barns at 107 kev.

Neutron logging sources. At least two other groups are working to develop neutron sources for well-logging purposes. High Voltage Engineering Corp. in cooperation with Well Surveys, Inc., has made a Van de Graaff generator contained in a tube 3 in. in diameter and 47 in. long. It generates accelerating potentials up to 200,000 volts and uses the D-T reaction to make an undisclosed number of neutrons. Under contract with Halliburton Oil Well Cementing Co., Tracerlab has been at work on a gas-discharge generator that uses the D-T reaction.



Schlumberger's sealed-tube neutron source designed for oil-well logging

Most neutron sources used so far, however, have been isotopic. About 1 curie in the form of radium-beryllium, polonium-beryllium, or actinium-beryllium is used. Well Surveys has irradiated radium in a Chalk River reactor and purified the product to make Ac^{227}. This is mixed with beryllium to make a better AcBe source. Ac^{227} has advantages over PoBe and RaBe sources in its relatively long half-life of 22 years and its small proportion of gamma radiation. Isotopic sources are usually limited to 10^6–10^7 n/sec, and with from one to several curies of activity, they require extensive shielding.

Gamma Gage for Dryness of Steam

Direct measurement of steam content at the output of a liquid-metal–water heat exchanger is useful but difficult. At the Windscale Works of the United Kingdom's Atomic Energy Authority A. P. Dixon has developed a method for measuring this quantity with a gamma source and an ion chamber.*

A 160-mc Tm^{170} source is placed at one side of a ¾-in. pipe and the ion chamber at the other. The geometry is chosen so that the bore of the pipe is just within the cone formed by lines from the source to the window of the chamber. With this arrangement the useful range is 0–2.5% steam by weight.

A scintillation detector was abandoned by Dixon because he found the ion-chamber system more stable. Stability is enhanced by bucking the detection chamber against another one exposed to the same source.

* A. P. Dixon, IGR-TN/W-489 (UK AEA, March, 1957).

BOOKS

Nuclear Engineering

By CHARLES F. BONILLA (McGraw-Hill Book Co., Inc., New York, 1957, xi + 850 pages, $12.50).

Reviewed by LEONARD TOPPER, New York Operations Office, U. S. Atomic Energy Commission, New York, N. Y.

A great many nuclear engineers will want to make room on their crowded bookshelves for Professor Bonilla's new volume. The individual chapters have been contributed by experts in the respective fields, and the result is a work of unusual scope.

Nuclear particles and physics is discussed by W. W. Havens, particle detection by C. S. Wu, radiation protection by G. Failla, reactor physics by R. W. Houston, reactor shielding by D. C. Peaslee, fluid flow and heat transfer by C. F. Bonilla, uranium metallurgy by G. L. Kehl, thermal-stress analysis by A. M. Freudenthal, instrumentation and control by J. W. Hoopes, power generation by T. Baumeister, a description of the types of power reactors by J. W. Landis and legal aspects by J. G. Palfrey. Although some important subjects are not mentioned, there is enough valuable material, not easily available elsewhere, to make it worth the purchase price.

The editor states that "Nuclear Engineering" is intended to be suitable as a text for a graduate course for engineers and physics majors, dealing with nuclear reactors and power plants. Such an audience would find the book very readable, but it would need to learn about such matters as exponential and critical assemblies from another source. The chapters devoted to engineering physics (reactor physics, shielding and control) are not on the same high level as those dealing with either nuclear physics or engineering. The instructor using this as a basic nuclear engineering book would probably want to bolster it with one of the texts on reactor physics. On the credit side, the chapters written by Bonilla himself are unusually detailed in treating both principles and a variety of applications to the design of specific reactor types, and the chapter by Freudenthal treats the subject of thermal-stress analysis in sufficient detail so that the applications may be developed by the instructor, or by the serious reader. The chapters on power generation and on reactor types are valuable and appropriate, and such material has not appeared in the existing textbooks.

"Nuclear Engineering" should be especially valuable to men entering this field from the more traditional areas of chemical and mechanical engineering, and it is expected that many of them will make use of it.

Clinical Use of Radioisotopes

T. FIELDS and L. SEED, editors (Year Book Publishers, Inc., Chicago, 1957, 455 pages, $9.50).

Reviewed by R. GARRETT, Physics Dept., Memorial Center for Cancer and Allied Diseases, New York, N. Y.

This book is essentially a manual of clinical procedure in the use of radioisotopes. The seventeen contributors have written chapters covering routine radioisotope techniques.

The editors in their preface point out that "this is a manual for practical application, not a textbook of detailed compilation of all known techniques and their variations." This has been done by selecting the particular procedure and methods that in their estimation are "the most representative of the techniques giving the most accurate results in their experience." The reader who wants further details and other techniques may refer to the bibliographies at the end of each chapter. Some of these are quite extensive and add materially to the value of the book.

The last 100 pages of the book consists of appendixes. These begin with a glossary followed by some formulas of use in radioactive decay calculations, particle counting and radiation dosage. This is followed by a set of decay tables for the principle radioisotopes used in tracer and therapy work and some useful facts concerning health physics and decontamination procedures. The appendix concludes with some examples of record and report sheets used in various laboratories.

The book has been divided up into four parts: (1) routine clinical diagnostic tests; (2) routine clinical therapy techniques; (3) planning and operating the radioisotope laboratory; (4) radiation safety.

Chapter 1, which is written by editors Seed and Fields, is titled "Thyroid Evaluation." This chapter is deserv-

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edly the longest in the book in view of the present extensive application of radioiodine for thyroid evaluation.

Four different tests of thyroid activity are first briefly described, (1) thyroid uptake, (2) rates of clearance and excretion, (3) urinary excretion, (4) plasma I^{131} and protein-bound I^{131}. Following this is a much longer section giving in great detail the recommended laboratory and clinical procedures for each of the above tests. For instance, the full procedure for preparing a tracer dose is worked through step by step from the opening of the container to the making of stock solutions of tracer doses.

Several pages are set aside to describe the findings of the conference on standardization of I^{131} thyroid-uptake methods, headed by Marshall Brucer of the Oak Ridge Institute of Nuclear Studies, held in September, 1956. It was found that there was considerable variation in uptake measurements as performed by different laboratories and the technique described is a result of exhaustive studies carried out by Brucer and his colleagues. The clinical procedure for each of the four tests is then described by first listing the apparatus required for the measurement followed by a concise outline of each step of the procedure. The chapter concludes with mention of clinical sources of error and the diagnostic significance of results.

The second chapter concerns isotope-dilution techniques. Topics treated are (1) blood volume using I^{131} human serum albumin, (2) red cell volume and survival using Cr^{51}, (3) ascitic fluid volume using I^{131} human serum albumin, (4) diagnostic tests with Co^{60} labeled vitamin B_{12}. Here again, the presentation stresses the practical aspect, each section being headed by a short description of the principles involved followed by a detailed account of technique. A glance through the list of some sixty references at the end of this chapter shows good coverage of the American work in the field. However, in the case of red cell volume using Cr^{51}, there are several excellent British papers not included here.

The remainder of part 1 contains chapters on tumor localization in the brain and eye, cardiovascular studies and radioautography.

Part 2 is concerned with routine clinical therapy technique. Topics covered are treatment of toxic goiter with I^{131}, therapy of blood diseases with P^{32}, cardiac therapy and the use of external beta irradiation. In common with other sections of the book there are given here tables of typical experimental results, also some diagrams and occasional photographs of apparatus to clarify the test.

Part 3 on planning and operating a radioisotope laboratory is of course an essential part of a manual of this sort. It begins with a very short review of physics followed by a chapter on the recommendations and requirements of the AEC for the medical use of radioisotopes and continues with an account of the properties and preparation of radioactive materials used in medicine and concludes with a chapter on the operation of various radiation-detection devices.

Part 4, the shortest in the book, contains much valuable information on radiation safety. The first chapter gives some general recommendations on radiation safety. The second gives more specific recommendations for laboratory personnel, including film-badge and pocket-chamber monitoring techniques. The final chapter presents an outline of radiation-safety techniques and procedures to be followed by hospital personnel handling patients who are undergoing therapy or to whom tracers have been administered. The chapter concludes with a section on the handling after death of patients containing radioisotopes.

BOOKS RECEIVED

Corrosion and Wear Handbook, edited by D. J. DePaul (McGraw-Hill Book Co., Inc., New York, 1957, ix + 293 pages, $6.00; also available as TID-7006, paperbound, from U. S. Government Printing Office, Washington, D. C., 293 pages, $2.25). Sponsored by Naval Reactors Branch, AEC Div. of Reactor Development. (*To be reviewed.*)

Isotopic Tracers in Biology, 3rd ed., by Martin D. Kamen (Academic Press, New York, xii + 474 pages, $9.50). (*To be reviewed.*)

Solvent Extraction in Analytical Chemistry, by George H. Morrison and Henry Freiser (John Wiley & Sons, Inc., New York, 1957, xi + 269 pages, $6.75). The stimulation solvent extraction has received from the nuclear field is indicated by the number of applications listed for nuclear materials, e.g., rare earths, actinide elements. The subject is well reviewed in four sections: principles, apparatus and

techniques, extraction systems and selected procedures for the elements.

Experimental Designs, 2nd. ed., by W. G. Cochran and G. M. Cox (John Wiley & Sons, Inc., New York, 1957, xiv + 611 pages, $10.25). This book serves as a handbook for the design of experiments, with the assumption that readers have some knowledge of analysis of variance. Examples are drawn mostly from biology and agriculture.

The Science of Engineering Materials, edited by J. E. Goldman (John Wiley & Sons, Inc., New York, 1957, xv + 528 pages, $12.00). This book is based on the Carnegie Conference on the Impact of Solid-State Science on Engineering Materials held in June '54 and sponsored by the American Society for Engineering Education and the National Science Foundation. Topics covered are structure of matter, and alloys, surfaces, magnetism, semiconductors and noncrystalline materials.

Theories of Nuclear Moments, by R. J. Blin-Stoyle (Oxford University Press, New York, 1957, 89 pages, $1.40). The predictions of several nuclear models advanced to account for the many electromagnetic moments that have been measured are compared with experimental data.

Introduction to Electrical Applied Physics, by N. F. Astbury (Philosophical Library, New York, 1957, xi + 241 pages, $10.00). After introducing electric and magnetic fields, electrical units and field equations, the author proceeds to discussions of circuits and measurements. The final chapters are devoted to electromechanical and electroacoustical systems, electron devices and electromagnetic waves.

Engineering Electronics, by John D. Ryder (McGraw-Hill Book Co., New York, 1957, x + 666 pages, $9.50). This book provides the fundamentals of electronics for nonradio electrical engineers. Such devices are covered as computers, voltage regulators, transistors, photoelectric devices and servomechanisms.

Builders of Continents, by David Meldrum (Exposition Press, New York, 1957, 198 pages, $3.50). The title suggests the magnitude of the author's vision for the constructive uses of atomic power. Projects he foresees for this new era include removal of the Greenland icecap, construction of a new continent in the North Atlantic and

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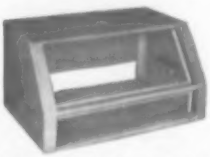

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Quantum Mechanics, by H. A. Kramers (Interscience Publishers, Inc., New York, and North-Holland Publishing Co., Amsterdam, 1957, xvi + 496 pages, $12.50). This book is a translation by D. ter Haar of the prewar monograph.

ALSO OF NOTE

Atomic Radiation. This comprehensive manual provides the worker in the nuclear field with an understanding of the hazards of radiation. In simplified terms, it discusses nuclear physics, biological effects of radiation, monitoring instruments, permissible radiation doses and medical treatment. 120 p. *Government Service Dept., RCA Service Co., Inc., Camden 8, N. J., $1.60.*

The Experimental Boiling Water Reactor (ANL-5607). A volume in the AEC Nuclear Technology Series, this book gives the design, operational characteristics and component description of the EBWR. Appendices give further details on design, calculations, operation and production. 233 p. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $2.25.*

Neutron Cross Sections (BNL-325, Suppl. 1). In this supplement to BNL-325, all data available up to Oct. 1, 1956, and fission data available up to Nov. 15, 1956, have been considered. Angular distributions are not included since they are given in BNL-400. Included are a thermal-cross-section table, resonance parameters and cross-section curves. 129 p. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $1.75.*

Proceedings of the Second RETMA Symposium on Applied Reliability. The reliability of applied components and systems, as well as reliability procedures followed by designers and manufacturers, are discussed in these proceedings of the June '57 symposium in Syracuse, N. Y. 93 p. *Engineering Publishers, P. O. Box 1151, New York 1, N. Y., $5.00.*

Alloy Casting Institute Data Sheets. Data sheets are available for 14 heat-resistant cast high alloys of iron giving room- and elevated-temperature properties, applications and design and fabrication considerations. These sheets supplement corrosion-resistance data

sheets issued in June '54. *Alloy Casting Institute, 286 Old Country Rd., Mineola, N. Y.*

Recruiting Practices and Procedures. This new set of regulations was formulated by the Committee on Ethics of the ASEE in cooperation with the Midwest College Placement Assoc. to correct difficulties in the recruitment of college seniors for engineering industries. *W. Leighton Collins, Secretary, American Society for Engineering Education, University of Illinois, Urbana, Ill., $0.25.*

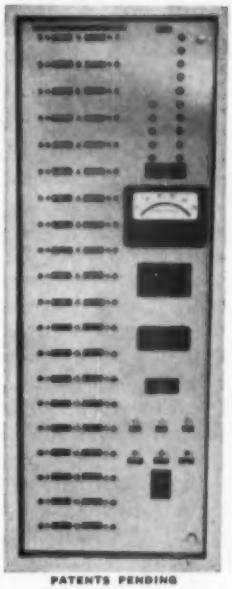
Proceedings of the Seventh National Conference on Standards. The conference was held in Oct. '56 in conjunction with the ASA annual meeting. Speakers in a session concerned with the need for nuclear standards included Morehead Patterson (AMF), W. A. Kitts (GE), Stuart McLain (ANL), Harvey Wagner (Detroit Edison) and Charles Crompton (National Lead). 103 p. *American Standards Association, DED-3, 70 E. 45 St., New York 17, N. Y., $4.00.*

A Review of the Air Force Materials Research and Development Program (PB 111648). This publication abstracts 145 reports of research conducted from July '55 to June '56. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., $2.50.*

Small Business and the Industrial Applications of Atomic Energy. This publication of the Small Business Administration discusses opportunities for small business in the fields of nuclear power and radioisotopes. *Small Business Administration, Lafayette Building, Washington, D. C.*

Consulting Services, 16th ed. This guide to members of the Association of Consulting Chemists and Chemical Engineers contains three sections: alphabetical listing by activity, detailed descriptions of consultants and alphabetical index to consultants. *ACC & CE Inc., Rm. 82, 50 E. 41st St., New York 17, N. Y., $1.00.*

Conference on Engineering Education and Nuclear Energy (TID-7527). These proceedings are of a conference held in Gatlinburg, Tenn., Sept. '56, sponsored by the AEC, ORINS, ORNL and ASEE. Papers by 29 speakers are included. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $1.00.*



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LETTERS

Burnout Calculation

DEAR SIR:

I enjoyed the article in the June issue of NUCLEONICS by Banister and Murray (B&M) on "Calculating Burnout Effects." However, I believe the authors have overstated the advantages of their method over perturbation techniques. The following points*† might be compared with their conclusions.

1. The application of perturbation theory is mathematically very simple. In particular, the tedious mathematical analysis of the B&M technique is not required to utilize perturbation theory. This point might be illustrated by comparing the perturbation analysis of p. 132 with the B&M analysis preceding it.

2. The first-order effects on reactivity are obtained immediately from the unperturbed flux with perturbation techniques, so that for small perturbations, one does not have to bother calculating the perturbed flux. Where large perturbations are present, neither first-order perturbation theory nor the B&M method can be relied upon, although possibly the B&M method is capable of more accuracy.

3. Perturbation theory allows the effect of each physical perturbation on the reactivity to be identified and its effect as a function of time to be easily followed. Effects with complicated flux dependence can be incorporated without great difficulty, so that it is not necessary to assume that cross-section changes due to burnup are proportional to the flux.

4. Since the B&M method assumes that the burnup effects are dependent upon the unperturbed flux, the effect of flux changes is only partially accounted for. Only in a limited sense does the B&M method account for the change in flux at the core-reflector-region face. Possibly more important are the approximations that may be necessary to mathematically use the B&M technique. Thus, while it may be justified to substitute $(-\nu^2)$ for $(\nabla^2 - \nu^2)$ in the interior of the core, as is done by B&M, it is not valid near the core-reflector interface. If such mathematical approximations are required, the B&M technique might lose any advantage in accuracy it has as compared to perturbation theory.

5. In actual numerical evaluation of reactor designs, perturbation theory requires a knowledge of the solution of only one type of problem (that of an unperturbed reactor). On the other hand, with the B&M approach, each time an effect with a different flux dependence is to be evaluated, one must in effect learn to solve a new type of problem. In actual reactor design work, where computers are extensively used, this is an important factor. Perturbation theory can be employed using standard reactor computer codes. In this regard, it should be mentioned that perturbation theory can be extended to any number of neutron groups with an increase in arithmetical difficulty but no increase in the analytical difficulty.

—B. WOLFE
San Jose, California

* The Reactor Handbook, AECD-3645, Vol. 1 Physics. U. S. Atomic Energy Commission, March 3, 1955.

† B. Wolfe, Burnup and Burnable Poisons in Highly Enriched Reactors, Meeting of American Nuclear Society, December 11, 1956.

DEAR SIR:

We wish to express our appreciation for Mr. Wolfe's remarks.

The basis for developing our method was that it could be readily understood by an individual who has studied mathematics only through differential equations, and who has not studied orthogonal functions or quantum mechanics. To this person, the concept and evaluation of adjoint fluxes as required in conventional two-group perturbation theory is *not* simple.

Perturbed fluxes are, of course, not needed for the calculation of reactivity values. One may, however, wish to estimate the degree of flux distortion, e.g., flattening as the result of a distributed coolant.

Those of Mr. Wolfe's other points that do not involve personal preference are well worth further study. It is suggested, however, that the standardization and exclusive use of existing computer codes may well serve as a deterrent to the development of new analytic methods.

—RAYMOND L. MURRAY,
Physics Department
North Carolina State College of Agriculture and Engineering
University of North Carolina
Raleigh, North Carolina

DEAR SIR:

First, I agree with Mr. Wolfe that, in the light of present-day computer techniques, our method may offer no particular advantage over perturbation

theory. However, as an instructional aid, it might give the student a better feeling for what he is doing.

I would also like to defend one important technical point. Our approximation of $\nabla^2 - \nu^2$ by $-\nu^2$, which Mr. Wolfe deplores, was made only for the bare reactor, where it is surely valid. For the reflected reactor, no such approximation was made.

As for our perturbed-flux calculations, we agree that only first-order changes are obtained; however, our critical condition takes account of the first-order change in the reflector flux caused by the first-order change in the core flux. This is not the case with first-order perturbation theory.

—Arthur W. Banister
U. S. Air Force Academy
Denver, Colorado

Dreadful Sorry, Clementine

Dear Sir:

In the July '57 issue of NUCLEONICS (p. 17), I came across a note stating, "A reactor core of plutonium fuel elements . . . world's first . . . was fabricated for use in EBR-1 . . . "

This was a somewhat surprising statement, for the Los Alamos Scientific Laboratory's "Clementine"—the world's first fast reactor—used plutonium fuel elements. As a matter of fact, in the Sept. '54 NUCLEONICS, you ran an article by E. T. Jurney, of the Laboratory's Physics Division, titled "Failure and Disassembly of Los Alamos Fast Reactor." The article even pictured one of the elements.

—Peter Mygatt
Information Office
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

[Editor's Note: Also, NUCLEONICS, Oct. '47, p. 78—"Fast-Neutron Pile Operating at Los Alamos." Even in the nuclear field, it is difficult having a "first" these days.]

Data Sheet 19 Errata

Dear Sir:

Two errors appear in Data Sheet No. 19 (NU, April '57, p. 84).

The last sentence in text should read: "Values of s are 0.65 from Fig. 1. . . ." Also, under "symbols," the expression for $Z(b_n,x)$ should be

$$Z(b_n,x) = \int_s e^{-b_n h} \cos\theta \, ds/4\pi h^2 a^2$$

—W. B. Lewis, Director
Atomic Energy Division
Phillips Petroleum Company
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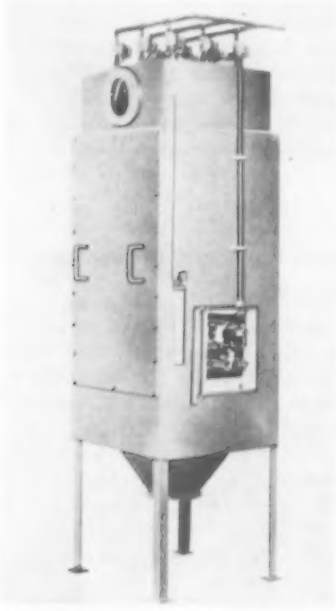

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Products Index

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Fume hood. Stainless-steel fume hood consists of two basic parts—inner stainless-steel shell with working surface and sash that slides on adjustable ball-bearing rollers. Sash frames either ¼-in. safety or explosion-proof glass.—Warren Corp., 2901 Brighton Rd., Pittsburgh 12, Pa.

Strain gage. Optical strain gage measures characteristics of materials subjected to temperatures up to 1,000° F. It is designed for precise measurement of tension and compression strains as small as 0.000004 in. Has two essential parts: autocollimator and estimating gage.—American Instrument Co., 8030 Georgia Ave., Silver Spring, Md.

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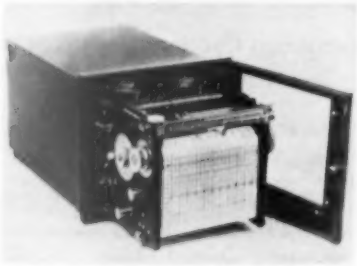

Two-Pen Potentiometer

Both pens on recording potentiometer write margin to margin on single 5-in. strip chart. Instrument has 0.5% accuracy on each pen and sensitivity 0.14% of scale span. Amplifiers are transistorized.—Westronics, Inc., 3605 McCart, Ft. Worth, Tex.

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Gage can be used with corrosive media. It operates at temperatures of −65° F to 300° F with <1.0% change. It is

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available in pressures ranging up to 10,000-psi absolute, gage, or differential.—Edcliff Instruments, PO Box 307, 1711 S. Mountain Ave., Monrovia, Calif.

Recording Oscillograph

Model CR-1B, a recording oscillograph, can record simultaneously up to 16 channels of phenomena at frequencies as high as 100,000 cps on single, 8-in. wide record. Has eight dual-gun, cathode-ray tubes with eight speeds from 3–400-in/sec. Unit uses standard commercial film and paper.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Digital Voltmeter

Model 460 series makes possible rapid accurate measurement of low-level d-c voltages from thermocouples, strain gages and transducers. Instrument displays voltage numerically on illuminated panels over 0.001–9.999-mv range; sensitivity is 3–5 μv.—Non-Linear Systems, Inc., Del Mar, Calif.

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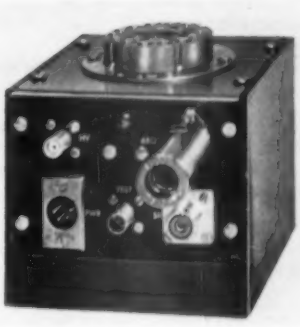
RADIATION DETECTORS AND ACCESSORIES



Photomultiplier Preamplifier

Model N-352 applied in scintillation spectroscopy; has a 70-ohm output impedance. Preamplifier is suitable for driving long coaxial cables.—Hamner Electronics Co., PO Box 531, Princeton, N. J.

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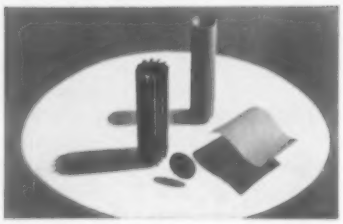

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position, windowless counter counts low activity β radition from C^{14}, S^{14}, etc., as well as α radiation from uranium-thorium series.—Atomlab, Inc., 489 Fifth Ave., New York 17, N. Y.

Chromatograph Scanner

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•

High-speed scaler. Model 379 permits counting pulses at high rates with low coincidence loss. Has <1 μsec resolving time; 50,000 cps rate; coincidence loss <1% at 10,000 random cpm. Scaler consists of input pulse height discriminator, fast scale of 10 using beam switching tube.—Franklin Electronics, Inc., Bridgeport, Pa.

Survey meter. Model 414 features single log scale for providing measurement from 3.0–3000 mr/hr. Instrument incorporates one-tube circuit design to detect and measure γ and β radiation.—Baird–Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Neutron detectors. Model VXN-1, enriched BF_3 proportional tube for counting thermal neutrons, has operating voltage of 1,700 volts with 250-volt-min. plateau. Another type,

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model VXN-2, works on recoil principle, with a polyethylene inner wall and ethylene filling and is used to count fast neutrons. Nominal operating voltage is 1,575 volts.—Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Photo multiplier. A 14-stage head-on-type photo multiplier is intended for use in scintillation counters. Tube 6810-A supersedes and improves on original 6810 tube, and covers 3,000–6,500 angstroms, with maximum response occurring at ~4,000 angstroms. —RCA Electron Tube Division, Harrison, N. J.

Neutron detector. Detector NE 400 is designed for scintillation counting of thermal neutrons. It is a boron polyester with ZnS activator. A neutron-to-gamma response of 100–1 for Po-Be neutrons and Co^{60} gammas is obtainable. Depending on detector's size, cost is $40–95.—Nuclear Enterprises, Ltd., 1750 Pembina Highway, Winnipeg 9, Canada.

Source calibrator. Model SC-56 can measure activities ranging from 5 μc to 500 mc in one of two well-type ionization chambers with ±5% overall accuracy. Source calibration is also useful as general purpose, semiportable, wide-range gamma-radiation meter.—Tracerlab, 1601 Trapelo Rd., Waltham, Mass.

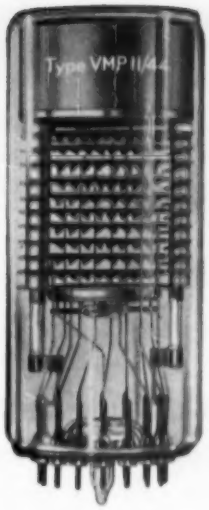
LITERATURE AVAILABLE

Mounted NaI(Tl) crystal specification sheets. Thirteen sheets included in set. These specification sheets are indicative of standard mountings available for thallium activated NaI and anthracene crystals.—Harshaw Chemical Co., 1945 East 97 St., Cleveland 6, Ohio.

Zirconium oxides, ram mixes and shapes and their characteristics, physical properties and prices.—Zirconium Corp. of America, Solon, Ohio.

Reactor systems to produce commercially useful electricity from nuclear energy reviewed in bulletin GER-1384. —General Electric Apparatus Sales Division, Schenectady 5, N. Y.

Boron stainless steel, new wrought austentitic alloy, for use in reactor shielding and control applications.—Superior Steel Corp., Carnegie, Pa.



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These tubes combine high sensitivity with exceptionally low noise and are therefore ideally suited to gamma spectroscopy as well as scintillation counting. The photocathode is formed on the flat end window and has highest sensitivity in the region of 4,200 A°. The range includes tubes having eleven or thirteen stages, Pyrex, kodial or quartz windows and cathodes of various diameters. The type illustrated has the following characteristics. Full details will be sent on request.

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Cathode diameter	44 mm.
Minimum cathode sensitivity	30 μA/L
Average cathode sensitivity	60 μA/L
Spectral response	S 11
Minimum overall sensitivity at 160 v per stage	200 A/L
Average volts per stage for 200 A/L	135 v.
Maximum dark current at 200 A/L	0.1 μA
Anode capacity	6 ppf
Window material	Pyrex
Maximum diameter	51 mm.
Overall length (seated)	122 ± 1 mm.
Base	B15B

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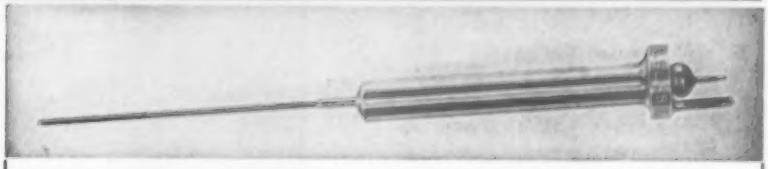

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SPECIFICATIONS

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Line Regulation	0.005%	$<$ 0.001%	$<$ 0.001%
Stability	0.05%/day	0.02%/day	0.005%/day

The output voltage range of the Model HV25 is 800 to 2500 volts. The Model HV15, with a range of 400 to 1500 volts, is also available. Both models provide 0 to 8 ma. of current and contain a polarity reversing switch on the rear apron.

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Automatic control with miniaturized non-indicating meter-relays in bulletin 104–A. 12 p.—Assembly Products, Inc., Palm Springs, Calif.

Hybrid junctions, flanges and adapters in catalog C457. 12 p.—Microwave Development Laboratories, Inc., 92 Broad St., Wellesley 57, Mass.

Portabe air pollution photometer in bulletin JM–1000–C. 8 p.—Phoenix Precision Instrument Co., 3803–05 N. Fifth St., Philadelphia 40, Pa.

Thermowells and their more than 5700 different combinations for protecting temperature sensing elements.—Thermo Electric Co., Saddle Brook, N. J.

Zirconium oxides, including applications, types, manufacturing methods and physical properties in bulletin 57.—Zirconium Corp. of America, Solon, Ohio.

INDUSTRY NOTES

▶**Keithley Instruments,** Cleveland, has created and filled three new executive posts: J. Lee Gibson, continuing as treasurer, will also be in charge of sales, production and finance; Julius Praglin to be vice-president for research; and William E. Koeblitz to be vice-president for engineering.

▶**National Radiac,** Newark, N. J., growers of scintillation crystals, will manufacture radiation detectors.

▶**Berkeley Division** of Beckman Instruments, Inc., has named Robert M. Ward manager. He was formerly division manager for Thompson Products, Inc.

▶**Allied Engineering & Production Corp.** has moved in Alameda, Calif. from its present location to new and larger quarters at 2421 Blanding St.

▶**Tracerlab** has opened a new subsidiary, Tracerlab (Holland) N. V., with offices in Amsterdam.

▶**Graver Tank & Mfg. Co.,** Chicago, and its parent firm, Phoenix Mfg. Co., Joliet, Ill., will be acquired by Union Tank Car Co., Chicago. Graver built the containment shell for EBWR.

▶**Schwarz Laboratories, Inc.,** Mt. Vernon, N. Y., radiochemical manufactures, will increase its available space by 25% through the acquisition of another building near its present headquarters.

NUCLEAR CAMPUS

• The University of Pennsylvania has received a $47,750 grant from AEC to purchase equipment for graduate instruction in nuclear technology. A nuclear measurements lab course will be offered during the spring 1958 semester when facilities are completed . . . Univ. of Maryland received a $250,180 grant from AEC for a combined experimental and theoretical research program in nuclear physics. Basic research tool will be a 3-Mev Van de Graaff accelerator.

• Oak Ridge Institute of Nuclear Studies is accepting applications for nuclear energy technology fellowships for the beginning of the second semester or quarter, or third quarter of the 1957–58 year. Also, the Oak Ridge traveling lecture program has more than 100 scientists prepared to visit southern universities to speak on over 150 topics.

Courses

Nuclear physics will be included in a sanitary science course to be given in the fall semester at the Illinois Institute of Technology, Chicago. It will be offered to graduate students in both the day and evening divisions.

A two-week, full-time course in **radiological safety** will be given Jan. 6–17, by New York Univ.'s Institute of Industrial Medicine. Fee is $90. Write: NYU Post-Graduate Medical School, 550 First Ave., New York 16, N. Y.

A course in **radioisotopes for technicians** will be held for eight consecutive Fridays starting Oct. 18 at the Queens Hospital Center. Fee is $100. Write: Philip Kahan, Queens Hospital Center, Jamaica 32, N. Y.

Next year's schedule of four-week courses in **basic techniques in using radioisotopes** at Oak Ridge Institute of Nuclear Studies is: Jan. 6–31; Feb. 3–28; May 19–June 13; June 16–July 11; Aug. 11–Sept. 5; and Sept. 8–Oct. 3. A bachelor's degree is required. Priority is given in summer courses to university personnel. Write: Ralph T. Overman, ORINS, PO Box 117, Oak Ridge, Tenn.

Baird-Atomic, Inc. will sponsor its 5th annual **direct reader school,** an instruction and refresher course in direct-reading spectrometers, in Cambridge, Mass., Oct. 28–Nov. 1.

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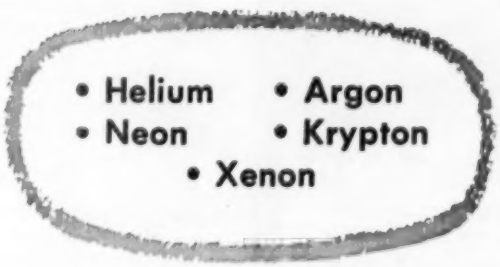

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NEWSMAKERS

Thomas H. Johnson has resigned as director of AEC's division of research to become manager of Raytheon Mfg. Co.'s research division. Prior to heading AEC's research program in the physical sciences for the past six years, Johnson was chairman of Brookhaven National Laboratory's physics department from 1947–51. In his Raytheon post he will direct theoretical and experimental research in nuclear physics, solid state physics, microwaves, etc.

Donald W. Kerst was named project leader of the controlled-fusion research program at the Hopkins Laboratory of General Dynamics' General Atomic division (NU, June '57, 17). Kerst, inventor of the betatron, was previously with the U. of Illinois, besides serving as technical director of Midwestern Universities Research Association, a nuclear-accelerator research group. During World War II he was leader of the Los Alamos group that constructed the first enriched-uranium reactor. He has also been a consultant to AEC on fusion research.

Carleton Shugg, general manager of General Dynamics' Electric Boat division, was elected a senior vice-president of the Corporation.

Nathan N. Woodruff, assistant manager for operations at AEC, Oak Ridge, has been transferred to the Commission's division of international affairs in Washington. He is succeeded by **Ray C. Armstrong,** director of the production division . . . **Wesley M. Johnson** was named director, technical liaison division, in AEC's New York Operations Office, succeeding **Hugh DiGiovanni,** resigned.

Los Alamos Scientific Laboratory has named **John M. Manley** as a research advisor. Manley was formerly professor of physics at the Univ. of Wash-

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ington and secretary of AEC's general advisory committee (1947–51).

Daniel Alpert, associate director of Westinghouse's research laboratories, has been appointed professor of physics and technical director of the control-systems laboratory at the Univ. of Illinois.

A nine-man board, four appointed and five elected, will act as the policy advisory board of Argonne National Laboratory. Appointed: **H. R. Crane,** professor of physics, Univ. of Michigan; **Robert C. Gunness,** vice-president, Standard Oil Co. (Indiana); **George A. Hawkins,** professor of engineering, Purdue Univ; and the **Very Rev. Theodore M. Hesburgh,** president, Notre Dame Univ. Elected: **John A. D. Cooper,** associate professor of biochemistry and assistant dean, Medical School, Northwestern Univ.; **Farrington Daniels,** professor and chairman, department of chemistry, Univ. of Wisconsin; **A. G. Norman,** professor of botany, Univ. of Michigan; **Frederick Seitz,** professor of physics, Univ. of Illinois; and **John H. Williams,** professor of physics, Univ. of Minnesota.

Tracerlab has promoted **W. Harrison Faulkner, Jr.,** to general manager of its engineering and development division. Faulkner, with Tracerlab since 1948, was formerly chief engineer of the industrial division.

Minnesota Mining & Mfg. Co. has promoted **James R. Johnson** to leader of its newly-formed nuclear research section. He will continue his previous assignment as coordinator of 3M's nuclear activities.

Roy B. Snapp has joined AMF Atomics as a divisional vice-president, with headquarters in Washington. Snapp was associated with AEC in several top-level posts from 1947 to 1954.

ASTRA has named **James T. Lence, Marvin K. Moss, John W. Stephenson** and **Charles A. Pelletier** to its staff.

Clarence Zener, director of Westinghouse's research laboratories, has been lecturing this summer at the international School of Physics at Varenna on Lake Como, Italy.

James A. Roemer was elected president of Reactive Metals, Inc., jointly owned by Mallory-Sharon Titanium Corp. (of which he is also president) and National Distillers.

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Sept. 9–13—International conference on neutron interactions with the nucleus, Columbia Univ., New York. Participants include I. I. Rabi, W. B. Lewis, H. A. Bethe, D. J. Hughes, E. P. Wigner. Contact R. W. Siegel, Physics dept., Columbia Univ., New York 27.

Sept. 22–27—Colloquium on mesons and recently-discovered particles, International Union of Pure and Applied Physics, in Venice. Contact Prof. Eligio Perucca, director, Politecnico, Turin, Italy.

Oct. 6–12—Ninth atomic energy course for management, National Industrial Conference Board, in Chicago (*Hotel Moraine-on-the-Lake*), Highland Park, Ill. Contact John McMahon, NICB, 460 Park Ave., NYC.

Oct. 7–9—Thirteenth annual National Electronics Conference, Chicago (*Sherman*). 100 technical papers, 240 exhibits. Contact F. A. Judd, NEC, 84 E. Randolph St., Chicago 1.

Oct. 7–11—Fall general meeting of American Institute of Electrical Engineers, Chicago (*Morrison*). More than 50 sessions. Contact AIEE, 29 West 39 St., New York 18.

Oct. 9—First of five lectures on elements of nuclear reactor metallurgy, American Society for Metals, at New York City Community College, 30 Pearl St., Brooklyn, N. Y. Successive lectures on **Oct. 23, Oct. 30, Nov. 13,** and **Dec. 4.** Fee: ASM members, $10; non-members, $15. Contact George L. Kehl, School of Mines, Columbia Univ., New York 27.

Oct. 7–12—French Metallurgical Week, French Metallurgical Society, Paris. Contact J. Pomey, president FMS, 25 rue de Clichy, Paris 9.

Oct. 28–Nov. 1—Autumn Nuclear Week in New York. Included are: **28–30th,** fourth annual meeting of the Atomic Industrial Forum (meetings *Plaza* and *Coliseum;* banquet *Waldorf*). **28–31st,** third annual Trade Fair of the Atomic Industry, sponsored by AIF (*Coliseum*). **28–30th** second winter meeting of the American Nuclear Society (*Henry Hudson*). **31st,** AEC-ANS-AIF reactor safety conference. And IRE's Professional Group on Nuclear Science holds fourth annual meeting **31–1st** (*Henry Hudson*).

Nov. 2–8—Second world metallurgical congress, American Society for Metals, Chicago. Contact W. H. Eisenman, congress secretary general, ASM, Cleveland. **3–8th,** second international conference on nondestructive testing. Contact G. H. Tenney, 704 47th St., Los Alamos, N. M.

Nov. 4–6—Unclassified meeting on role of analytical chemistry in nuclear reactor technology, Oak Ridge National Laboratory, Gatlinburg, Tenn. Contact D. D. Cowen, ORNL, PO Box X, Oak Ridge, Tenn.

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Nov. 18–20, 19–21—Eleventh and twelfth atomic energy course on industrial uses of radioisotopes, National Industrial Conference Board, Rye, N. Y. (*Westchester Country Club*). Fee $285. Contact John J. McMahon, NICB, 460 Park Ave., New York 22.

Dec. 1–6—Annual meeting, American Society of Mechanical Engineers, New York (*Statler, McAlpin*). Contact L. S. Dennegar, ASME, 29 West 39 St., New York 18.

Dec. 24–26—Conference on nuclear sizes and density distribution, National Science Foundation, Palo Alto, Calif. Contact Robert Hofstadter, Stanford Univ., Palo Alto.

Jan. 7–10—Third international symposium on radioisotopes in clinical application and research, Bad Gastein, Austria. Contact Second Medical Clinic, Vienna Univ., Vienna, Austria.

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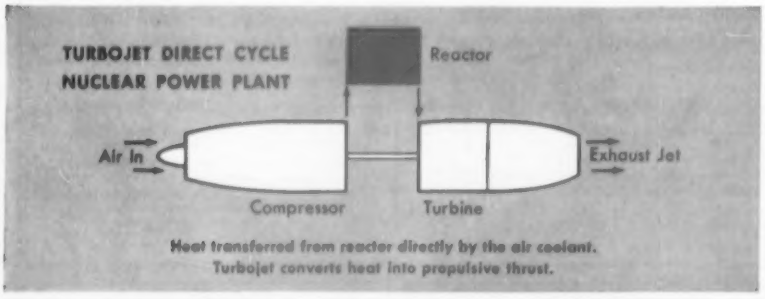

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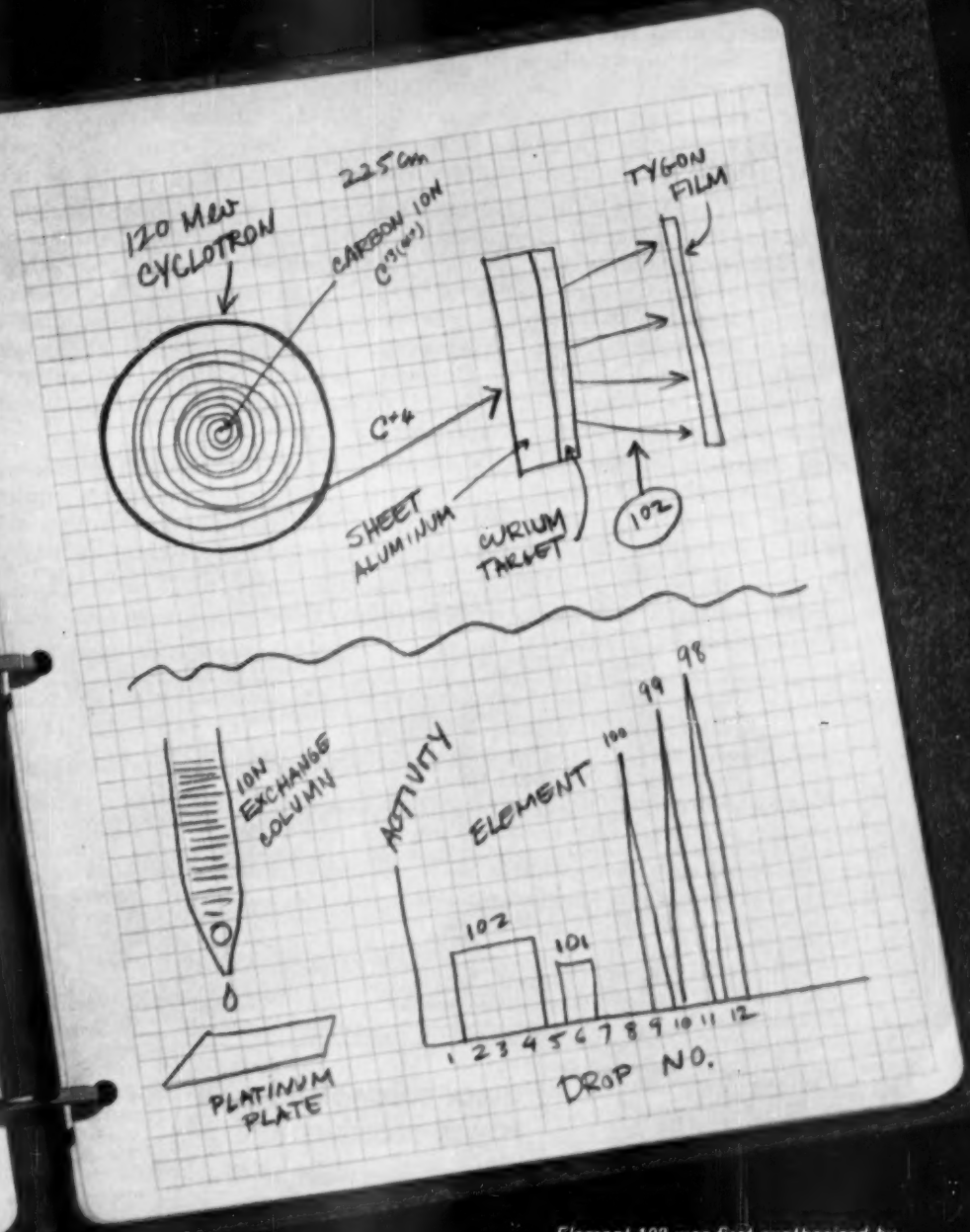

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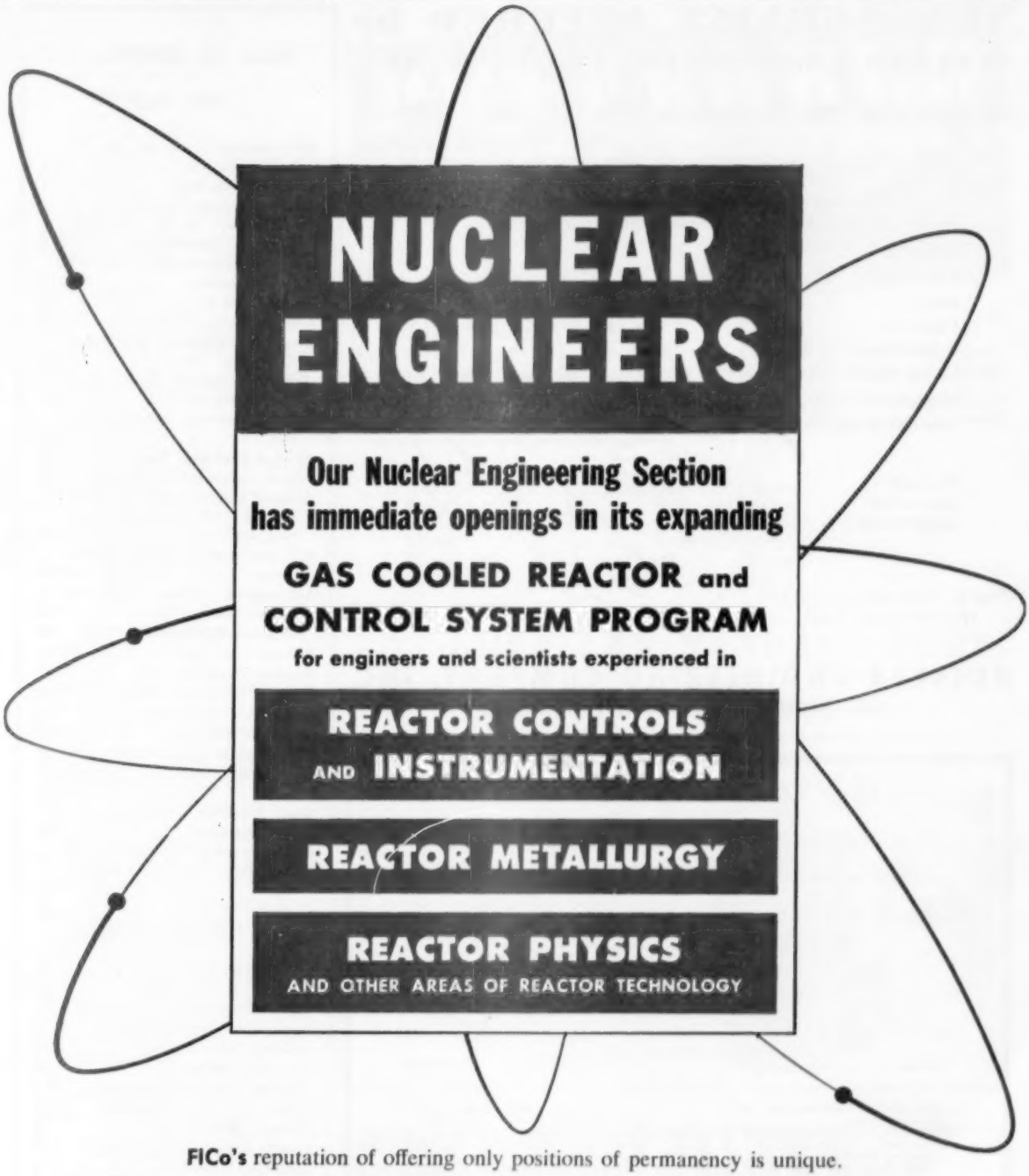

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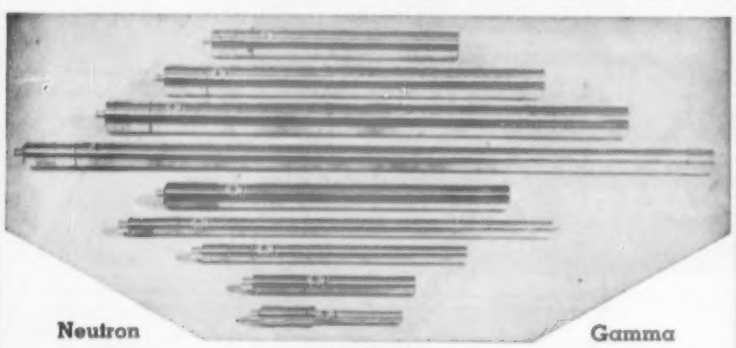

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For additional general information request Bulletin 314. For specific information on your requirements, provide application details.

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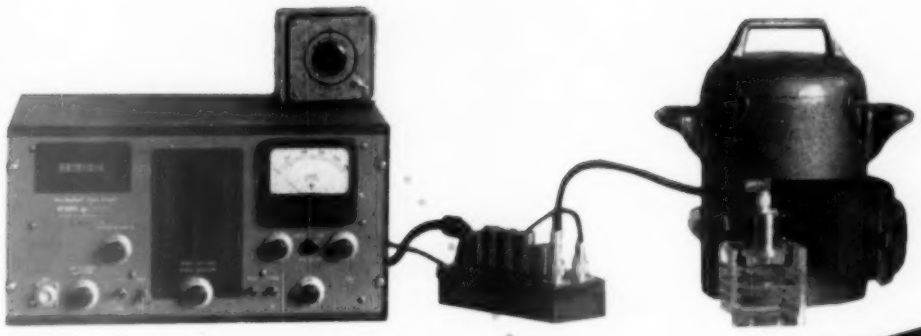

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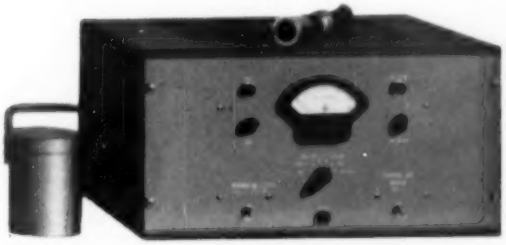

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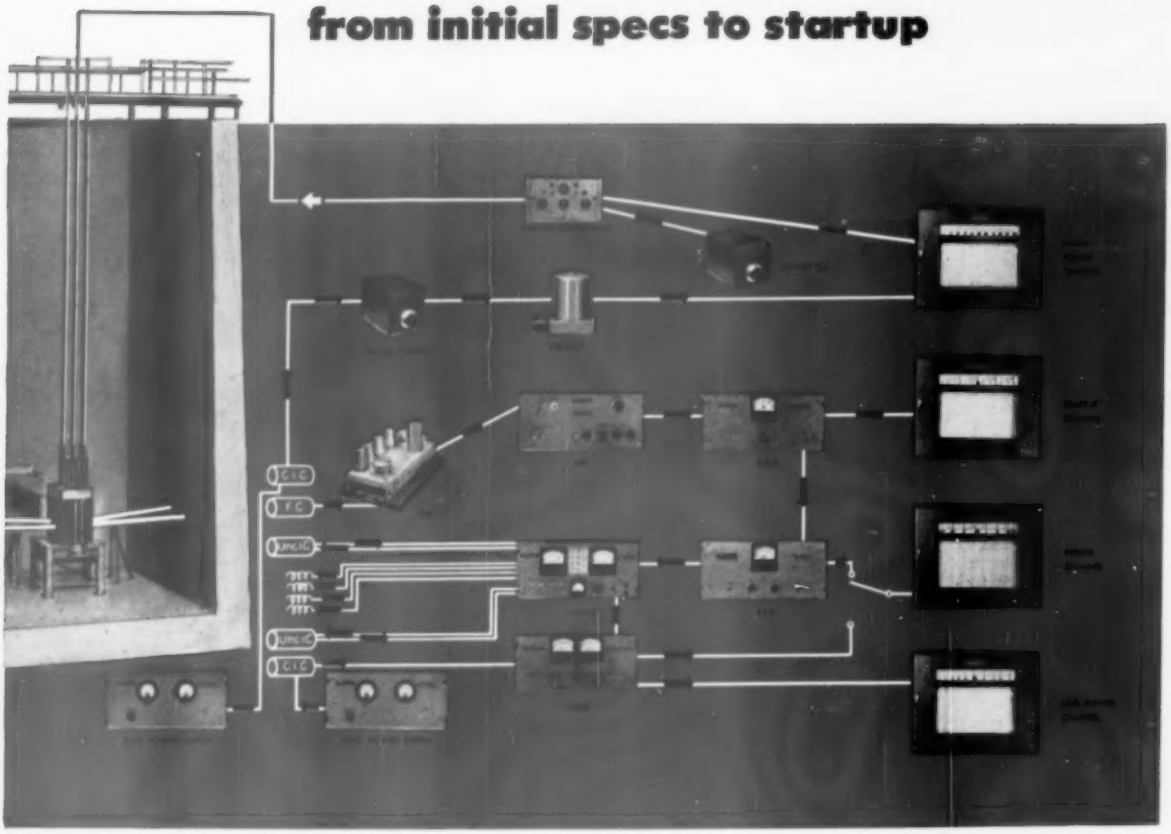

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